भारतीय मानक
Indian Standard

IS 17128 (Part 3) : 2021

स्वचल वाहन — वाहन गति की परीक्षण पद्धतियाँ

भाग 3 अस्थाई अनुक्रिया परीक्षण पद्धति — खुला लूप एवं बंद लूप परीक्षण

Automotive Vehicles — Vehicle Dynamics Measurements Test Procedure

Part 3 Transient Response Test Procedure — Open Loop and Closed Loop Test

ICS 43.020

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Automotive Braking Systems, Vehicle Testing and Performance Evaluation Sectional Committee, TED 04

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Automotive Braking and Steering System, Vehicle Testing and Performance Evaluation Sectional Committee had been approved by the Transport Engineering Division Council.

The dynamic behaviour of a road vehicle is a most important part of vehicle safety. Any given vehicle, together with its driver and the prevailing environment, forms a unique closed-loop system. The task of evaluating dynamic behaviour is therefore very difficult since, there is a significant interaction between these driver-vehicle-environment elements, each of which is complex in itself. A complete and accurate description of the behaviour of the road vehicle must necessarily involve information obtained from a number of tests of different types. Since, they quantify only a small part of the complete vehicle handling characteristics, the results of these tests can only be considered significant for a correspondingly small part of the overall dynamic behaviour.

Less data is acquired to obtain relationship between overall vehicle dynamic properties versus actual driving patterns.

The basic purpose of the standard is to understand the vehicle characteristic under controlled standard test conditions.

Test and tyres conditions have a strong influence on test results. Only vehicle dynamic properties obtained under identical test and tyre conditions are comparable.

Therefore, it is not recommended to use this standard for regulatory purposes.

This Indian Standard is published in five parts. The other parts in this series are:

Part 1	General test conditions
Part 2	Steady state test procedures
Part 4	Ride comfort measurements
Part 5	Subjective evaluation — Vehicle ride, handling, steering and tyre evaluation.

In the formulation of this standard considerable assistance has been derived from the following International Standards:

a) ISO 4138 : 2004 Passenger cars — Steady state circular driving behaviour — Open loop test methods
b) ISO 7401 : 2003 Road vehicles — Lateral transient response test methods — Open loop test methods
c) ISO 7975 : 2006 Passenger cars — Braking in a turn — Open loop test method
d) ISO /TR 8725 : 1988 Road vehicles — Transient open loop response test method with one period of sinusoidal input
e) ISO /TR 8726 : 1988 Road vehicles — Transient open loop response test method with pseudo-random steering input
f) ISO 9815 : 2003 Road vehicles — Passenger car and trailer combinations — lateral stability test
g) ISO 12021-1 : 1996 Road vehicles — Sensitivity to lateral wind — Part 1: Open loop test method using wind generator input
h) ISO 15037-1 : 2019 Road vehicles — Vehicle dynamics test methods — Part 1: General conditions for passenger cars
j) ISO 17288-2 : 2004 Passenger cars – Free steer behaviour — Part 2: Steering pulse open-loop test method

The composition of the Committee responsible for the formulation of this standard is given in Annex D.

In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 1960 ‘Rules for rounding off numerical values (*revised*)’.

Indian Standard

AUTOMOTIVE VEHICLES — VEHICLE DYNAMICS MEASUREMENTS TEST PROCEDURE

PART 3 TRANSIENT RESPONSE TEST PROCEDURE — OPEN LOOP AND CLOSED LOOP TEST

1 SCOPE

1.1 This Indian standard (Part 3) defines and specifies open-loop and closed loop test methods for determining the transient driving behaviour in frequency and time domain. The parameters, such as steering wheel angle, steering wheel torque, roll angle, yaw rate, body side slip angle, lateral acceleration, longitudinal velocity, pitch angle, damping and response time etc. are used to evaluate the vehicle response and controllability during transient maneuvers tests.

1.2 The maneuvers included in this standard may not represent the real driving conditions but they are useful for obtaining the vehicle response and control parameters in controlled environment with specified test conditions. This standard is applicable for M1 category of vehicles as defined in IS14272.

1.3 This standard provides guidelines for various test methods used to evaluate transient response behaviour in controlled environment with specified test conditions. Test and tyre conditions have a strong influence on test results. Only vehicle dynamic properties obtained under identical test and tyre conditions are comparable.

Therefore, it is not recommended to use this standard for regulatory purposes.

2 REFERENCES

The following standards contain provisions, which through reference in this text, constitute provisions of this standard. At the time of publication the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

IS/ISO No.	*Title*
14272 : 2011	Automotive vehicles — Types — Terminology (*first revision*)
17128 (Part 1) : 2019	Automotive vehicles — Vehicle dynamics test methods: Part 1 General test conditions
ISO 15037-1 : 2019	Road vehicles — Vehicle dynamics test methods — Part 1: General conditions for passenger cars

3 TERMS AND DEFINITIONS

3.1 Open Loop System — For the purpose of vehicle characterization, only the open loop system is used. Open loop refers to vehicle response to the particular steering inputs without any driver's feedback.

3.2 Closed Loop System — Vehicle stability and controllability is the measure of vehicle and driver combination. Test driver along with the vehicle forms a closed loop system. Driver observes vehicle direction/position and accordingly corrects the input (steering, brake and accelerator) to achieve the desired path. Normally path feedback is used in closed loop system. The test results may vary based on the test driver's response to the closed loop system.

In future intelligent systems may perform the closed loop test without human intervention.

4 PRINCIPLE

4.1 Test Methods

4.1.1 *Closed Loop*

Method 1 that is, severe lane-change maneuver is used for closed loop test.

4.1.2 *Open Loop*

Following methods are used for closed loop test:

a) *Method 2* — Lateral transient response test methods

b) *Method 3* — Braking in a turn

c) *Method 4* — Quantification of on-center handling

d) *Method 5* — Free-steer behaviour

Severe lane change is closed loop path tracking test method determine road-holding ability of passenger cars. Since test performed on the severe lane-change track quantifies only a small part of complete handling characteristics, the results obtained on this test track can only be considered significant for a correspondingly small aspect of overall vehicle-dynamics behaviour. In closed loop the driver has a great influence on test results.

Open loop methods yield lateral, longitudinal and straight line behaviour of the vehicle. open-loop test method determine the free control stability of a passenger car measured during the transient behaviour.

5 VARIABLES

5.1 Reference System

The provisions for reference system are given in IS 17128 (Part 1).

5.2 Measurement

List of parameters to be measured is provided in Table 1. Measure the variables given in Table 2.

6 MEASURING EQUIPMENT

6.1 Description

The variables selected for test purposes shall be measured using appropriate transducers and the data recorded on a multi-channel recording system having a time base. Typical operating ranges, and recommended maximum errors of the transducer and recording system are given in Table 1 of IS 17128 (Part 1).

6.2 Transducer Installation

The transducer installation shall comply with **4.2** of IS 17128 (Part 1).

Install gyro at vehicle's reference point, the vertical gyro axis should be coincident or parallel to the vehicle's vertical (Z) axis. In case of any doubt, test equipment instruction manual to be referred.

6.3 Data Processing

The provisions given in **4.3** of IS 17128 (Part 1) shall apply.

Table 1 Transient response test (Open and Closed Loop Test)

(*Clause* 5.2)

Transient Response Test (Open and Closed Loop Test)					
	Test Name	**Test Method**	**Options**	**Test Condition**	**Parameters to be Measured**
1	Severe lane-change	Closed loop	Double lane-change	At different speeds	Steering wheel angle, Steering torque, roll angle, roll rate, yaw rate, lateral
			Obstacle avoidance		
2	Lateral transient response test methods	Open loop	Time domain	At different speeds	Steering-wheel angle, lateral acceleration, yaw velocity, longitudinal velocity, roll angle, sideslip angle, lateral velocity, steering wheel torque
			Step input		
			Sinusoidal		
			Frequency domain		
			Random input		
			Pulse input		
			Continuous sinusoidal		
3	Braking in a turn	Open loop	Standard radius of 30 m	At different deceleration rates	Moment of brake application, steering-wheel angle, lateral acceleration, longitudinal acceleration, longitudinal velocity, yaw velocity, sideslip angle, lateral velocity
4	Quantification of on-centre handling	Open loop	Weave test	At constant velocity and different lateral acceleration	Steering-wheel angle, lateral acceleration, yaw velocity, longitudinal velocity, steering wheel angular velocity, steering wheel
			Transition test		Steering-wheel angle, lateral acceleration, yaw velocity, longitudinal velocity, steering wheel angular velocity, steering wheel
5	Free-steer behaviour	Open loop	Steering-release	At different speeds	Longitudinal velocity, lateral acceleration, yaw velocity, steering wheel angle
			Steering-pulse		Steering wheel angle, yaw velocity, longitudinal velocity, lateral acceleration

Frequency band width in the entire measurement system including sensors and recording devices should be 10 - 100 Hz.

7 TEST CONDITIONS

Test conditions shall be in accordance with IS 17128 (Part 1) (Annex B). General data on the test vehicle shall be recorded as specified in IS 17128 (Part 1) (Annex A).

The tyre type, tyre brand, any special equipment on the test vehicle, any deviation in type or operating condition of components from the manufacturer's specification, the odometer reading at the beginning and end of the test, any other condition that may affect test results shall also be recorded on the test report for general data as specified in IS 17128 (Part 1) (Annex B).

8 TEST PROCEDURE

8.1 Warm-up

The warm-up shall be carried out in accordance with **6.1** of IS 17128 (Part 1).

8.2 Initial Driving Condition

The conditions shall be in accordance with **6.2** IS 17128 (Part 1).

8.3 General Test Description

All necessary variables shall be recorded throughout the maneuver. The method chosen shall be noted in the section for test method specific data on the test report for test conditions IS 17128 (Part 1) (Annex B). Longitudinal velocity increments can be reduced at higher level of acceleration based on vehicle stability.

The test should be repeated several times so that the results can be examined for repeatability and averaged.

8.4 Method 1 Closed Loop Test — Severe Lane-change Maneuver

Following two options are available:

a) Double lane change, and
b) Obstacle avoidance.

Severe lane change is closed loop path tracking test method determine road-holding ability of passenger cars. Since, test performed on the severe lane-change track quantifies only a small part of complete handling characteristics, the results obtained on this test track can only be considered significant for a correspondingly small aspect of overall vehicle-dynamics behaviour. In closed loop the driver has a great influence on test results.

8.4.1 *Option 1 — Severe Lane Change Maneuver : Double Lane Change*

8.4.2 *Description*

The severe lane change maneuver is a well-known test method which is generally used for subjective evaluation of vehicle dynamics. Since test performed on the severe lane change track quantifies only a small part of complete handling characteristics, the results obtained on this test track can only be considered significant for a correspondingly small aspect of overall vehicle-dynamics behaviour.

Table 2 Variables, Typical Operating Ranges and Recommended Maximum Errors

(*Clause* 5.2)

Variable (1)	Typical Operating Range[a)] (2)	Recommended Maximum Error of Combined System[b)] (3)
Steering-wheel angle	± 50	± 0.1°
Steering-wheel torque	± 0,1 N.m	± 0.1 N. m
Yaw velocity	± 10 °/s	± 0.1°/s
Longitudinal velocity	0 m/s to 50 m/s	± 0.5 m/s
Lateral acceleration	± 5 m/s^2	± 0.1 m/s^2
Steering wheel angular velocity	± 100 °/s	± 1°/s

Transducers for measuring some of the listed variable are not widely available and are not in general use. Many such instruments are developed by users. If any system error exceeds the recommended maximum value, this and the actual maximum error shall be stated in the test report (*see* ISO 15037-1, Annex A).

[a)] These transducer ranges are appropriate for the standard test conditions and might not be suitable for non-standard test conditions.

[b)] The values for maximum errors are provisional until more experience and data are available.

NOTE — The method chosen to determine lateral acceleration could require the measurement of additional variables (yaw velocity, vehicle roll angle, or sideslip angle) for use in the computation.

NOTE — The severe lane change maneuver test method was previously described in a Technical Report (ISO/TR), and until now has not been dealt with in an International Standard. The reason for this was that the driver has a great influence on test results. The test method itself has now been placed in an informative annex, permitting the specification for the test track to be published as an International Standard. No closed-loop test has so far been specified in an International Standard for the purpose of investigating vehicle dynamics.

8.4.3 *Dimensions of the Double Lane Change Assessment Zone*

Figure 1 shows the assessment zone for the double lane change layout. However, overall test track length to be ensured before start of the test based on entry and exit speed of the test vehicle as well as the vehicle capability to accelerate and brake within the safe limit.

8.4.4 *Marking of the Double Lane Change Track*

The double lane change track shall be marked with cones of minimum height 500 mm, suitable cones are depicted in Fig. 2. The cones shall be placed at points specified by Fig. 3, and the track limits shall be tangential to the base circles of the cones.

8.4.5 *Procedure*

The recommended speed of entry into section 1 is (80 ± 3) km/h. Higher or lower speeds may be used. The speed of entry shall be mentioned in the test report. Over the test course the throttle position shall be held as steady as possible. Further constraints, such as steer strategy used, may be applied. The speed of exit from section 5 shall be stated in the test report.

Some typical uses of this test are to:

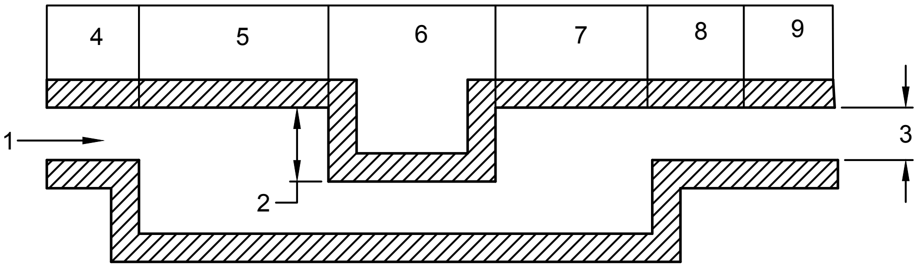
a) evaluate, with respect to time, the steer input or motion parameters;

b) evaluate driver-control strategies; and

c) subjectively evaluate the vehicle.

8.4.5.1 *General*

Only skilled drivers shall be allowed to perform the test. A passage is faultless when none of the cones positioned as specified in Fig. 3 have been displaced. The measuring distance, for instance to evaluate the average speed, starts at the beginning of section 1 and finishes at the end of section 5. The gear or selector position engaged during the test shall be stated in the test report.



Key

1 driving direction
2 land offset
3 width

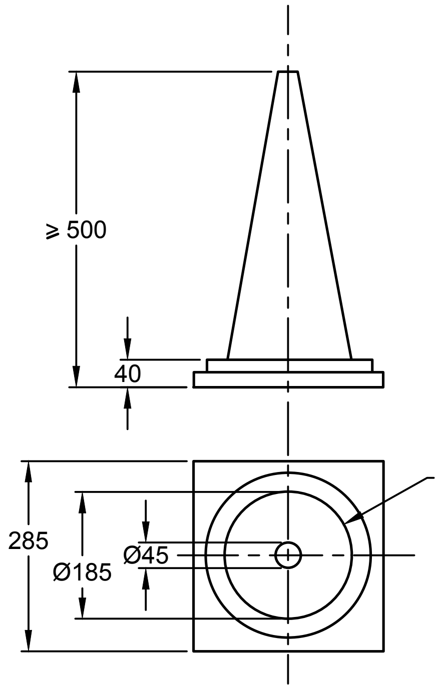
4 section 1
5 section 2
6 section 3

7 section 4
8 section 5
9 section 6

SECTION	LENGTH	LANE OFFSET	WIDTH
1	15	—	1.1 X VEHICLE WIDTH + 0.25
2	30	—	—
3	25	3.5	1.2 X VEHICLE WIDTH + 0.25
4	25	—	—
5	15	—	1.3 X VEHICLE WIDTH + 0.25
6	15	—	1.3 X VEHICLE WIDTH + 0.25

All dimensions are in meters

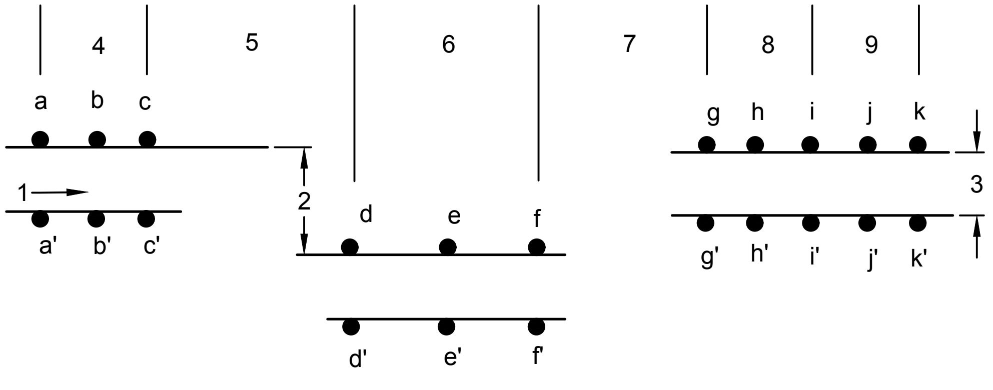
FIG. 1 DOUBLE LANE-CHANGE TRACK AND DESIGNATION OF SECTIONS



Key
1 base circle of cone.

All dimensions are in millimetre.

FIG. 2 CONE USED FOR MARKING DOUBLE LANE CHANGE TRACK



Key
1 driving direction
2 land offset
3 width
4 section 1
5 section 2
6 section 3
7 section 4
8 section 5
9 section 6

FIG. 3 PLACING OF CONES FOR MARKING THE DOUBLE LANE CHANGE TRACK

8.5 Method 2 — Obstacle Avoidance Maneuver

8.5.1 *Dimensions of the Double Lane Change Assessment Zone*

Figure 1 shows the assessment zone for the double lane change layout. However, overall test track length to be ensured before start of the test based on entry and exit speed of the test vehicle as well as the vehicle capability to accelerate and brake within the safe limit.

8.5.2 *Marking of the Obstacle Avoidance Track*

The obstacle avoidance track shall be marked with cones of a minimum height of 500 mm (*see* Fig. 5). The cones shall be placed at the points shown in Fig. 6, and the track limits shall be tangential to the base circles of the cones.

8.5.3 *Procedure*

a) Enter section 1 with the highest gear position that guarantees a minimum engine speed of 2 000 r/min (for vehicles with automatic transmission, place selector lever in the drive position, D).

b) At 2 m after entering section 1 (*see* Fig.7), release the throttle and drive the remaining distance in the throttle-released position.

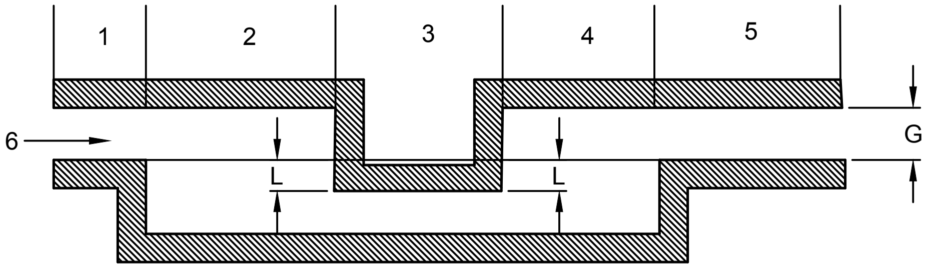
In order to keep the test procedure as reproducible as possible, the initial longitudinal velocity of the vehicle is to be measured at the end of section 1 and mentioned in the test report.

8.5.4 *Limitations*

Owing to driver influence (driving strategy) in this closed loop test, there is no possibility of an objective measurement of vehicle dynamics data; only subjective evaluation is recommended.

The different paths followed in different tests bring about a considerable scatter in measured velocities. Although longitudinal dynamics are restricted (throttle-off after entering section 1), this does not lead to the desired minimization of the measured velocities. Therefore, no ranking on the basis of the vehicle velocity and no minimum velocity limit for vehicles is permitted.

NOTE — Because of these limitations, this standard defines only the dimensions of the test track for the subjective evaluation of vehicle dynamics.



Key

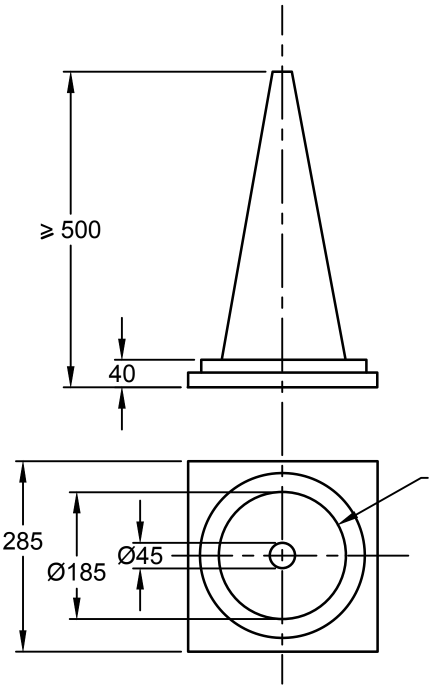
1 section 1	4 section 4	7 lane offset
2 section 2	5 section 5	
3 section 3	6 driving direction	

Section	Length	Lane offset	Width (b)
1	12	—	1.1 × vehicle width + 0.25
2	13.5	—	—
3	11	1	Vehicle width + 1
4[1]	12.5	—	—
5	12	—	1.3 × vehicle width + 0.25, but less than 3 m

[1] To ensure high lateral accelerations at the end of the track, section 4 is shorter than section 2.

NOTE — All dimensions are in millimetres.

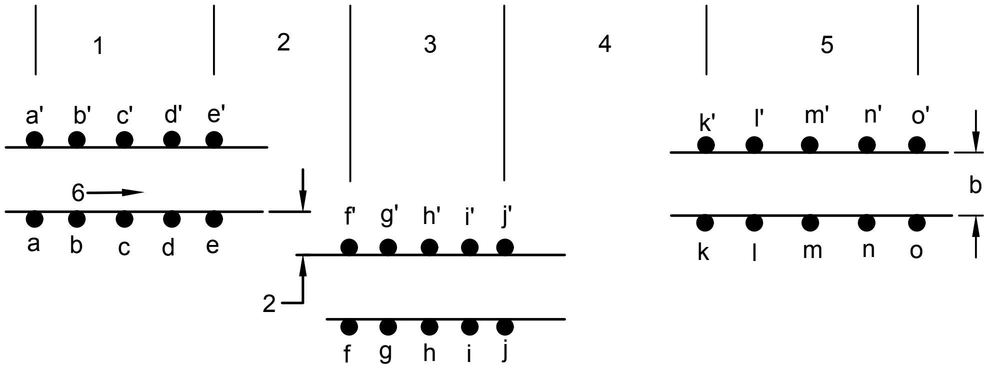
FIG. 4 OBSTACLE AVOIDANCE TRACK WITH DESIGNATION OF SECTIONS



Key
1 base circle of cone.

All dimensions are in millimeter.

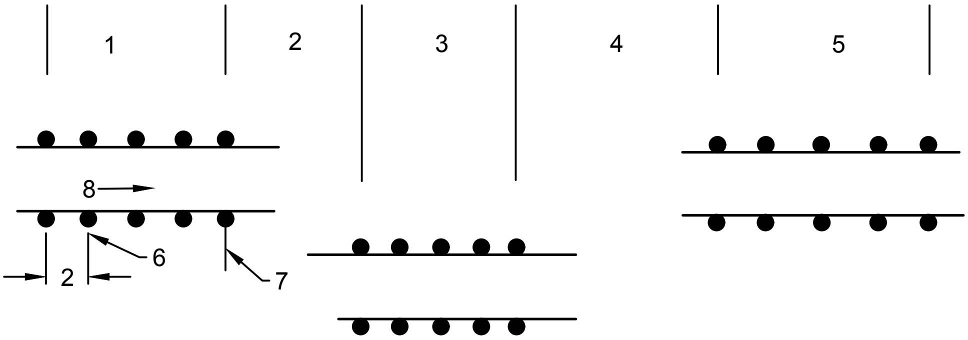
FIG. 5 CONE USED FOR OBSTACLE AVOIDANCE TRACK DELIMITATION



Key
1 section 1
2 section 2
3 section 3
4 section 4
5 section 5
6 driving direction
7 lane offset

NOTE — Letters indicate placement of individual cones.

FIG. 6 PLACING OF CONES FOR MARKING OBSTACLE AVOIDANCE TRACK



Key

1 section 1	4 section 4	7 measurement of the longitudinal velocity
2 section 2	5 section 5	8 driving direction
3 section 3	6 throttle off	

All dimensions are in millimeter.

FIG. 7 THROTTLE-OFF AND MEASUREMENT OF VEHICLE LONGITUDINAL VELOCITY

8.6 Open Loop Test Method 2 — Lateral Transient Response Test Methods

Following two options are available:

- a) Option 1 : Time domain
  - 1) Step input, or
  - 2) Sinusoidal.
- b) Option 2 : Frequency domain
  - 1) Random input,
  - 2) Pulse input, or
  - 3) Continuous sinusoidal.

8.6.1 *Description*

The method of data analysis in the frequency domain assumes that the vehicle has a linear response. This is unlikely to be the case over the whole range of lateral accelerations of interest.

The standard method of dealing with such a situation is to restrict the input to a sufficiently small range such that linear behaviour can be assumed. If necessary, testing can be performed with several ranges of inputs that, together, cover the entire range of interest. The primary object of these tests is to determine the transient response behaviour of a vehicle. Characteristic values and functions in the time and frequency domains are considered necessary for characterizing vehicle transient response.

Important characteristics in the time domain are:

- a) time lags between steering-wheel angle, lateral acceleration and yaw velocity;
- b) response times of lateral acceleration and yaw velocity;
- c) lateral acceleration gain (lateral acceleration divided by steering-wheel angle);
- d) yaw velocity gain (yaw velocity divided by steering-wheel angle); and
- e) overshoot values.

These characteristics show correlation with subjective evaluation during road driving. Important characteristics in the frequency domain are the frequency responses, that is, amplitudes and phases of :

- a) lateral acceleration related to steering-wheel angle; and
- b) yaw velocity related to steering-wheel angle.

8.6.2 *Test Methods*

There are several test methods for obtaining these characteristics in the domains of time and frequency, the applicability of which depends in part on the size of the test track available.

These test methods are optional, but at least one of each domain type should be performed. The methods chosen shall be indicated in the general data specified in Annex A and in the presentation of test results specified in Annex B.

It is possible that the characteristic values of lateral acceleration gain and yaw velocity gain, obtained by the different test methods, may not be comparable, owing to one or more of the following circumstances:

- a) linear *versus* non-linear vehicle behavior;

b) periodic *versus* non-periodic steady-state condition; and
c) steady state *versus* dynamic vehicle behaviour.

8.6.3 *Variables*

8.6.3.1 The following variables shall be determined:

a) steering-wheel angle,
b) lateral acceleration,
c) yaw velocity, and
d) longitudinal velocity.

8.6.3.2 The following variables may be determined:

a) roll angle,
b) sideslip angle,
c) lateral velocity, and
d) steering-wheel torque.

These variables, defined in 17128 (Part 1), are not intended to comprise a complete list.

8.6.4 *Measuring Equipment*

Please refer **4** of IS17128 (Part 1).

8.6.5 *Step Input*

8.6.5.1 *Test procedure*

Drive the vehicle at the test speed in a straight line. The initial speed shall not deviate by more than 2 km/h from the test speed. Starting from a 0°/s ± 0.5°/s yaw velocity equilibrium condition, apply a steering input as rapidly as possible to a preselected value and maintain at that value for several seconds after the measured vehicle motion variables have reached a steady state. In order to keep the steering input short, relative to the vehicle response time, the time between 10 percent and 90 percent of the steering input should not be greater than 0.15 s. No change in throttle position shall be made, although speed may decrease. A steering wheel stop may be used for selecting the input angle.

Take data for both left and right turns. All data shall be taken in one direction followed by all data in the other direction. Alternatively, take data successively in each direction for each acceleration level, from the lowest to the highest level, this being preferable with respect to tyre wear and symmetrical vehicle stress. Record the method chosen in the test report (*see* **Annex A**).

Data shall be taken throughout the desired range of steering inputs and response variable outputs.

Determine the steering-wheel angle amplitude by steady-state driving on a circle the radius of which gives the preselected steady-state lateral acceleration at the required test speed. The standard steady-state lateral acceleration level is 4 m/s^2. Additional levels of 2 m/s^2 and 6 m/s^2 may be used.

Perform all test runs at least three times.

8.6.5.2 *Data analysis*

8.6.5.3 *Response time*

The transient response data reduction shall be carried out such that the origin for each response is the time at which the steering-wheel angle change is 50 percent complete. This is the reference point from which all response times are measured. Response time is thus defined as the time, measured from this reference, for the vehicle transient response to first reach 90 percent of its new steady-state value (*see* Fig. 8).

8.6.5.4 *Peak response time*

The peak response time is the time, measured from the reference point, for a vehicle transient response to reach its peak value (*see* Fig. 8).

In some instances, system damping can be so high that a peak value cannot be determined. If this occurs, data sheets should be marked accordingly.

8.6.5.5 *Overshoot values*

The overshoot values are calculated as a ratio, the difference of peak value and steady-state value divided by steady-state value.

8.6.5.6 *Data presentation*

General data shall be presented in accordance with Annex A.

8.6.5.6.1 *Time histories*

The time histories of variables used for data evaluation shall be plotted. If a curve is fitted to any set of data, the method of curve fitting shall be described in the presentation of results in Annex B.

Plot the time histories of steering-wheel angle, lateral acceleration and yaw velocity for each measured lateral acceleration level in the form, as shown in Fig. 31.

8.6.5.6.2 *Time response data summary*

Record the following values in accordance with Table 10 for each combination of test speed and lateral acceleration:

a) steady-state yaw velocity response gain;
b) lateral acceleration response time;
c) yaw velocity response time;
d) lateral acceleration peak response time, *Max*;
e) yaw velocity peak response time, *Max*;
f) overshoot value of lateral acceleration; and
g) overshoot value of yaw velocity.

8.6.6 *Sinusoidal Input*

8.6.6.1 *Test procedure*

Drive the vehicle at the test speed in a straight line. The initial speed shall not deviate by more than 2 km/h from the test speed. Starting from a 0 °/s ± 0.5 °/s yaw velocity equilibrium condition, apply one full period sinusoidal steering-wheel input with a frequency of 0.5 Hz. An additional frequency of 1 Hz should also be used. The amplitude error of the actual waveform compared to the true sine wave shall be less than 5 percent of the first peak value. No change in throttle position shall be made, although speed may decrease.

Take data while the steering-wheel is rotated, initially both to the left and to the right. All data shall be taken in one direction followed by all data in the other direction. Alternatively, take data successively in each direction for each acceleration level, from the lowest to the highest level. Record the method chosen in the test report (*see* Annex A).

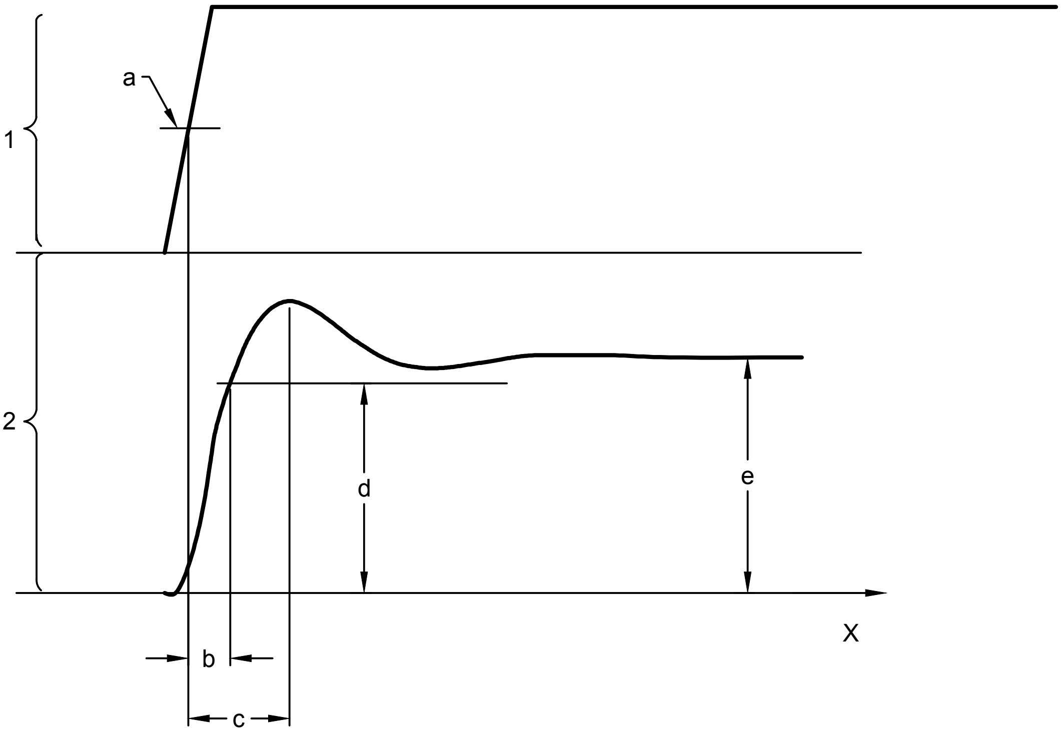
Increase the steering-wheel input stepwise up to a magnitude sufficient to produce the desired lateral acceleration. The standard lateral acceleration level is 4 m/s^2. Additional acceleration levels of 2 m/s^2 and 6 m/s^2 and up to the adhesion limit as given in IS 17128 (Part 1) may be used. Perform at least three test runs for each combination of speed and steering.

8.6.6.2 *Data analysis*

a) *Lateral Acceleration* — Lateral acceleration in this test is defined as the first peak value of the lateral acceleration time history, corrected for vehicle roll angle.

b) *Yaw Velocity* —Yaw velocity in this test is defined as the first peak value of the yaw velocity time history.

c) *Time Lags* — The time lags between the variables steering-wheel angle, lateral acceleration and yaw velocity are calculated for the first and second peaks by means of cross-correlation of the first and second half-waves, respectively (positive and negative parts of the time history).



Key
1 steering-wheel input
2 vehicle response time
x time
a 50% level
b response time ; t
c peak responce time ; tmax.
d 90% steady state
e steady state

FIG. 8 RESPONSE TIME AND PEAK RESPONSE TIME

d) *Lateral Acceleration Gain* — Lateral acceleration gain is calculated as the ratio of the lateral acceleration [in accordance with **8.6.9.2 (b)**] to the corresponding peak value of the steering-wheel angle.

e) *Yaw Velocity Gain* — Yaw velocity gain is calculated as the ratio of the yaw velocity [according to **8.6.9.2 (c)**] to the corresponding peak value of the steering-wheel angle.

8.6.6.3 *Data presentation*

General data shall be presented in accordance with Annex A.

The time histories of variables used for data evaluation shall be plotted. If a curve is fitted to any set of data, the method of curve fitting shall be described in the presentation of results in accordance with Annex B-2

8.6.6.4 *Time histories*

Plot the time histories of steering-wheel angle, lateral acceleration and yaw velocity for each measured lateral acceleration level as shown in Fig. 32.

Time response data summary

Calculate the following test data (*see* Table 11) as mean values ± standard deviation:

a) time lags between steering-wheel angle and lateral acceleration:
    1) first peak, or
    2) second peak.
b) time lags between steering-wheel angle and yaw velocity:
    1) first peak, or
    2) second peak.
c) lateral acceleration gain, and
d) yaw velocity gain.

8.6.6.5 *Data as functions of lateral acceleration*

If optional lateral acceleration levels are measured, it is useful to present data as functions of lateral acceleration.

8.6.7 *Random Input*

8.6.7.1 *Test procedure*

Make the test runs by driving the vehicle at the required test speed, while making continuous inputs to the steering-wheel, up to predetermined limits of steering-wheel angle.

The test shall cover a minimum frequency range of 0.2 Hz to 2 Hz. Optionally, the frequency range may also be extended above and below these limits.

Do not use mechanical limiters of the steering-wheel angle, if existing, because of their effect on the harmonic content of the input. It is also important that the input be continuous, as periods of relative inactivity will seriously reduce the signal-to-noise ratio.

To ensure adequate high-frequency content, the input should be energetic. To ensure enough total data, capture at least 12 min of data, unless confidence limits indicate that a shorter time is sufficient. Ideally, all data should be accomplished in a continuous run, but practical considerations can prevent this for two reasons. Firstly, the test track could be insufficiently long to permit a continuous run of such a length at the required test speed. Secondly, the computer used to analyse the data might not be large enough to handle all the data at once. In either case, data may be captured using a number of shorter runs of at least 30 s duration.

For each test run, maintain the longitudinal velocity within a tolerance of ± 3 km/h of the desired test speed.

Determine the steering-wheel angle limits by steady-state driving on a circle, the radius of which gives the preselected steady-state lateral acceleration at the required test speed. The standard steady-state lateral acceleration level is 3 m/s^2 or less, as necessary to remain within the range in which the vehicle exhibits linear properties. Optionally, higher lateral acceleration levels may also be used, provided the vehicle remains in the linear range.

8.6.7.2 *Data analysis*

The data processing can be carried out using a multi-channel real time analyzer or a computer with the appropriate software.

8.6.7.2.1 *Preliminary analysis*

A Fourier analysis shall be made of the steering-wheel angle time history. The result shall be displayed as a graph of the input level relative to that at the lowest frequency *versus* frequency, as shown in Annex B.

This graph shall be examined to ensure adequate frequency content. The recommended ratio between maximum and minimum steering-wheel angle should be not greater than 4:1 (12 dB). If this ratio is greater, the results may be discarded or, if used, the extent of the ratio shall be recorded in the test report (*see* Annex B).

Further data processing The data shall then be processed using equipment appropriate for producing the transfer function amplitude and phase information together with the coherence function for the following combinations of input and output variables:

a) lateral acceleration related to steering-wheel angle; and
b) yaw velocity related to steering-wheel angle.

If data has not been captured in a continuous run, calculate the auto and cross-spectral densities for each run.

The results of individual runs shall then be averaged. The averaging function used shall be recorded in the test report (*see* Annex A).

8.6.7.2.2 *Data presentation*

General data shall be presented in accordance with Annex A.

If a curve is fitted to any set of data, the method of curve fitting shall be described in accordance with Annex B.

8.6.7.2.3 *Frequency response functions*

For each pair of input and output variables, the frequency response (that is, gain and phase-angle functions) shall be presented on a graph as shown in Fig. 33. The figure shall be completed with the number and length of the data sequences, the averaging function, the digitizing rate and the windowing function used.

The coherence function shall also be presented on the graph (*see* Fig. 33). This coherence function quantifies the amount of correlated information in relation to noise present in the data. To obtain close confidence limits, it is necessary to have high coherence levels and a large number of averages.

Experience shows that coherence for yaw velocity related to steering-wheel angle shall be above 0.95 in the range from 0.2 to 2 Hz for reproducible and reliable test results.

8.6.8 *Pulse Input*

8.6.8.1 *Test procedure*

Drive the vehicle at the test speed in a straight line. The initial speed shall not deviate by more than 2 km/h from the test speed. Starting from a 0 °/s ± 0.5 °/s yaw velocity equilibrium condition, apply a triangular waveform steering-wheel input, followed by 3 s to 5 s neutral steering-wheel position. No change in throttle position shall be made, although speed may decrease.

Use a pulse width of 0.3 s to 0.5 s. Make efforts to minimize the overshoot of the steering-wheel angle and the differences between zero references before and after the steering-wheel input to values ≤ 5 per cent of the peak input level. The zero reference is the steady-state value before and after the steering-wheel input.

Determine the amplitude of the steering-wheel input by steady-state driving on a circle, the radius of which gives the preselected steady-state lateral acceleration at the required test speed. The standard steady-state lateral acceleration level is 4 m/s^2 or less as necessary to remain within the range in which the vehicle exhibits linear properties. Optionally, higher lateral acceleration levels may also be used, provided the vehicle remains in the linear range. Perform all test runs at least three times.

8.6.8.2 *Data analysis*

The data processing can be carried out using a multi-channel real time analyser or a computer with the appropriate software.

8.6.8.2.1 *Preliminary analysis*

A fourier analysis shall be made of the steering-wheel angle time history. The result shall be displayed as a graph of the input level relative to that at the lowest frequency versus frequency as shown in Annex B.

8.6.8.2.2 *Further data processing*

The data shall then be processed using appropriate equipment to produce the transfer function amplitude and phase information together with the coherence function for the following combinations of input and output variables:

a) lateral acceleration related to steering-wheel angle; and
b) yaw velocity related to steering-wheel angle.

The transfer functions of at least three test runs shall be averaged.

8.6.8.2.3 *Data presentation*

General data shall be presented in accordance with Annex A. Time histories of variables used for data evaluation shall be plotted. If a curve is fitted to any set of data, the method of curve fitting shall be described in the test report in accordance with Annex B.

8.6.8.2.4 *Frequency response functions*

For each pair of input and output variables, the frequency response (that is, gain and phase-angle functions) shall be presented on a graph, as shown in Fig. 34. The graph shall be completed with the number and length of the data sequences, the averaging function, the digitizing rate and the windowing function used.

The coherence function shall also be presented on the graph (*see* Fig. 34). This function quantifies the amount of correlated information in relation to noise present in the data. To obtain close confidence limits, it is necessary to have high coherence levels and a large number of averages.

8.6.9 *Continuous Sinusoidal Input*

8.6.9.1 *Test procedure*

Drive the vehicle at the test speed in a straight line. The initial speed shall not deviate more than 2 km/h from the test speed. Starting from a 0 °/s ± 0.5 °/s yaw velocity equilibrium condition, apply at least three periods of sinusoidal steering-wheel input with the predetermined steering-wheel angle amplitude and frequency. No change in throttle position shall be made, although speed may decrease.

Increase the steering frequency in steps. The test shall cover a minimum frequency range of 0.2 Hz to 2 Hz.

Optionally, the frequency range may also be extended above and below these limits.

Determine the steering-wheel angle amplitude by steady-state driving on a circle the radius of which gives the preselected steady-state lateral acceleration at the required test speed. The standard steady-state lateral acceleration level is 4 m/s^2. Additional levels of 2 m/s^2 and 6 m/s^2 may be used.

8.6.9.2 *Data analysis*

a) *Amplitude* — The amplitude of the steering-wheel angle, lateral acceleration and yaw velocity is defined as the mean value of the amplitudes following the first period.

   All amplitudes shall be taken during the maneuvers when the vehicle is in a periodic steady-state condition.

b) *Lateral Acceleration Gain* — Lateral acceleration gain shall be calculated as the ratio of the lateral acceleration amplitude to the steering wheel angle amplitude.

c) *Yaw Velocity Gain* — Yaw velocity gain shall be calculated as the ratio of the yaw velocity amplitude to the steering-wheel angle amplitude, both amplitudes being in accordance with IS 17128 (Part 1).

8.6.9.3 *Phase angle*

Phase angles between the steering-wheel angle and the lateral acceleration and yaw velocity shall be determined from the time histories after the first period, when the vehicle is in a periodic steady-state condition.

8.6.9.4 *Data presentation*

General data shall be presented as given on the summary form in Annex A.

Time histories of variables used for data evaluation shall be plotted. If a curve is fitted to any set of data, the method of curve fitting shall be described in the presentation of results as in Annex B.

Frequency response functions for each pair of the input and output variables, lateral acceleration and yaw velocity, the frequency response (that is, gain and phase-angle functions) shall be presented on a graph as shown in Fig. 34.

8.7 Method 3 — Braking in a Turn

8.7.1 *Description*

The purpose of this test is to examine the effect of braking on course holding and directional behaviour of a vehicle. Specifically, the method determines how the steady-state circular response of a vehicle is altered by braking action only.

The initial conditions are defined by constant longitudinal velocity and by a circle with a given radius, as specified by the constant-radius test method of IS 17128 (Part 1). The steering-wheel angle required for the steady-state circular run shall be constantly maintained during the entire test. During the test, the driver input and the vehicle response are measured and recorded. From the recorded signals, characteristic values are calculated.

8.7.2 *Variables*

8.7.2.1 Measure and determine the following variables:

a) brake application time ($t0$);
b) steering-wheel angle (δH);
c) lateral acceleration (aY);
d) longitudinal acceleration (aX);
e) longitudinal velocity (vX);
f) yaw velocity ($\mathrm{d}\psi/\mathrm{d}t$); and
g) sideslip angle (β) and/or lateral velocity (vY).

   NOTE — Strictly speaking, test results based on lateral acceleration should not be used for comparison of the performance of different vehicles. This is because lateral acceleration is measured at right angles to the intermediate X-axis and not perpendicular to the vehicle path. To overcome this difficulty, lateral acceleration can be corrected for vehicle sideslip angle, which gives the centripetal acceleration. However, the extent of this correction is not likely to exceed a few percent and may generally be neglected.

8.7.2.2 It is recommended that the following variables be determined:

a) pressure at master cylinder output or in the brake circuit which activates at least one of the front wheel brakes (pB);
b) wheel rotation speed ($\omega 1 - \omega 4$);
c) contact switch mounted directly on the brake pedal; and
d) sensor for the brake pedal force.

The variables are defined in IS 17128 (Part 1), except for stopping distance and the moment of brake application, $t0$, which is the instant at which the brake pedal is operated. The actuation of the brake pedal may be determined by the use of a contact switch mounted directly on the brake pedal or a sensor for the brake pedal force which set a trigger signal when the brake pedal force exceeds 10 N.

8.7.3 *Measuring Equipment:*

8.7.3.1 *Description*

Table 1 of IS 17128 (Part 1) shall apply with the following additions as given in Table 3:

8.7.4 *Test Procedure*

8.7.4.1 *Run-in program for newly installed brakes (pads/shoes)*

The brake linings (pads/shoes) shall be conditioned following the recommendations of the vehicle manufacturer. If manufacturer's recommendations are not available, the brake linings shall be conditioned using one of the following procedures:

8.7.4.1.1 For vehicles with disc/disc braking systems, a total of 60 brake applications shall be performed. From an initial vehicle speed of 100 km/h, the vehicle shall be decelerated to approximately 20 km/h at the following approximate deceleration rates:

a) 2 m/s^2 for the first 15 brake applications;
b) 3 m/s^2 for the next 15 brake applications; and
c) 5 m/s^2 for the final 30 brake applications.

8.7.4.1.2 For vehicles with disc/drum or drum/drum braking systems, a total of 200 brake applications shall be performed. From an initial vehicle speed of 100 km/h, the vehicle shall be decelerated to approximately 20 km/h at the following approximate deceleration rates:

a) 2 m/s^2 for the first 50 brake applications;
b) 3 m/s^2 for the next 50 brake applications; and
c) 5 m/s^2 for the final 100 brake applications.

During these brake applications, brake disc and/or brake drum temperatures must not exceed 200 °C. The tyres used for running in the brakes must not be used for subsequent braking distance measurements.

8.7.4.2 *Warm-up*

The warm-up shall be carried out in accordance with **6.1** of IS 17128 (Part 1).

In addition to warming up the braking system, five full stops should be performed from an initial speed of about 100 km/h. In each of these stops, brake actuation should be sufficient to cause the anti-lock braking system to be active throughout the majority of the stop. To avoid excessive strain on the brakes, the temperature of the brake discs (drums) should be below 120°C at the beginning of each single stop.

8.7.4.3 *Brake temperature*

The temperature of the front brake discs (drums) shall be between 80°C and 120°C, and the rear brake discs (drums) shall be less than 120 °C before each test run. If necessary, the brakes shall be cooled between runs. The installation of reliable temperature sensors is recommended to monitor the brake temperatures.

8.7.4.4 *Initial driving condition*

The initial driving conditions shall be in accordance with **6.2** of IS 17128 (Part 1).

The initial driving conditions for a steady-state circular run, as specified in **7.2** of ISO 15037-1 shall apply with the initial conditions according to the combinations of radii and lateral acceleration given in Table 4. As it is known that the significance of the results and the discrimination between different vehicles increase with increasing test speed, the standard radius of this path shall be 100 m. Additional radii ranging from 30 m to 200 m may be used and shall be noted in the figures of Annex A. Because of the importance of the initial

Table 3 Variables, Typical Operating Ranges and Recommended Maximum Errors

(*Clause* 8.7.3.1)

Sl No.	Variable	Typical Operating Range	Recommended Maximum Error of the Combined Transducer/Recorder System
(1)	(2)	(3)	(4)
i)	Brake application time	—	0.05 s
ii)	Pressure of braking system	30 MPa [a)]	± 0.3 MPa
iii)	Wheel rotation speed	0 per second to 200 per second	± 2 per second

[a)] 1 MPa = 10 bar = 106 N/m^2.

Table 4 Initial Test Condition

(*Clauses* 8.7.4.4 and 8.7.4.5)

Condition	Radius	Lateral Acceleration		Corresponding Longitudinal Velocity	
	m	m/s^2	tolerance, percent	km/h	tolerance, percent
Standard	100	5	± 10	81	± 5
Optional	30 to 200	5	± 10	44 to 114	± 5

driving conditions, especially for brake tests, the throttle position shall be observed. For the time interval from $t1$ to $t2$ (*see* Fig. 2 of ISO 15037-1) the standard deviation of the throttle position shall not exceed 10 per cent of its mean value.

NOTE — Results of different radii are not comparable.

The initial combination of one radius and one lateral acceleration given in Table 2 could be widened by additional test runs with lateral accelerations other than 5 m/s^2, mainly by steps of 1 m/s^2.

8.7.4.5 *Performance of the braking procedure*

When the initial steady-state driving condition has been reached, the steering wheel is fixed by a mechanical device or, alternatively, is firmly held by the driver. The accelerator pedal shall be released and brakes applied as quickly as possible.

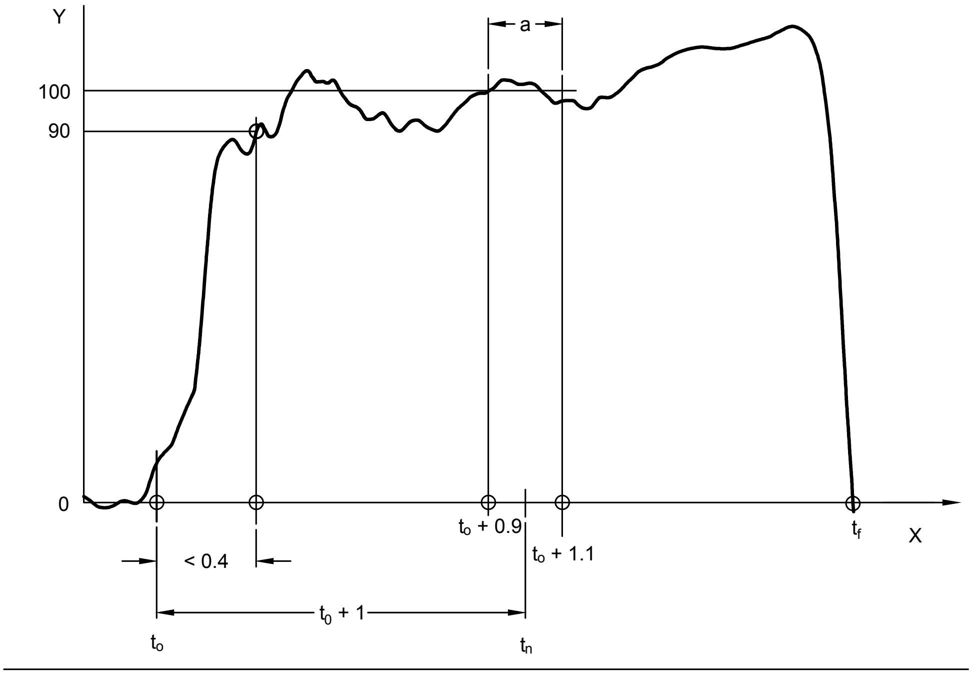
For vehicles with manual transmission, the test shall be performed in the highest gear compatible with the conditions of the test speed given in Table 4. The clutch may be disengaged immediately or at the end of the test run. The option chosen (gear position and clutch disengagement) shall be indicated in the test report (*see* Annex C).

For vehicles with automatic transmission, the standard drive mode shall be used. The position of the transmission lever and the selected driving programme shall be recorded in the test report (*see* Annex C).

Cars with adaptive gear selection or CVT may use different gears or ratios at a given speed. For such cars, engine speed shall be recorded for the purpose of determining gear ratio. It shall be recorded in the test report.

The actuation of the brake-pedal or the brake light switch is considered as the moment of brake application, $t0$. During braking, the pressure in the braking system or the brake-pedal force or the brake-pedal travel shall be kept as constant as possible (an adjustable stop under the brake-pedal may serve) and the steering wheel shall be fixed until the test run is finished.

The test runs for a combination of radius and lateral acceleration defined in Table 4 shall be made at increasing levels of longitudinal acceleration, until on vehicles with conventional braking system, lock up of at least one of the front wheels occurs (if possible). The test may be continued beyond this point resulting in further wheels locking until lock up of all wheels has occurred, but testing under these conditions may result in rapid and large changes of tyre characteristics, which may cause wide variations in test results. On vehicles equipped with an antilock braking system, the test shall be continued until the peak value of mean longitudinal acceleration at time t_n (*see* Fig. 9) is detected.



X time, t(s)
y longitudinal acceleration (per cent)
a time interval for evaluation (see 9.4.1)

FIG. 9 DEFINITION OF TIMES

The minimum braking action shall correspond to a mean longitudinal acceleration of 2 m/s^2 and shall be increased by increments of not more than 1 m/s^2. If the results vary rapidly with the longitudinal acceleration, smaller increments should be selected.

NOTE — Depending on the conditions of load, there could be a certain risk of rollover. If necessary, some safety device is recommended.

8.7.4.6 *General test description*

All necessary variables shall be recorded throughout the maneuver. Data shall be taken for both clockwise and anti-clockwise steering turns.

For tests utilizing discrete increments of speed, radius or steering-wheel angle, all of the test data may be taken in one turn direction followed by all the data in the other turn direction, as experience has shown that this minimizes data scatter. However, to obtain more even tyre wear and reduced tyre heating, data may be taken in alternating turn directions at each test speed/ radius/steering-wheel angle.

8.7.4.7 *Data analysis and presentation of results*

8.7.4.7.1 General data on the test vehicle shall be presented on a summary form using the general data test report contained in Annex A. The general test conditions shall be presented using the test conditions contained in Annex B of IS 17128 (Part 1).

8.7.4.7.2 *Time histories*

For every test run, time histories of the variables listed in **5** of IS 17128 (Part 1) shall be presented. Apart from their evaluation purposes, the time histories serve to monitor correct test performance and functioning of the transducers.

8.7.4.7.3 *Braking action*

8.7.4.7.4 *Reference point in time*, t_0

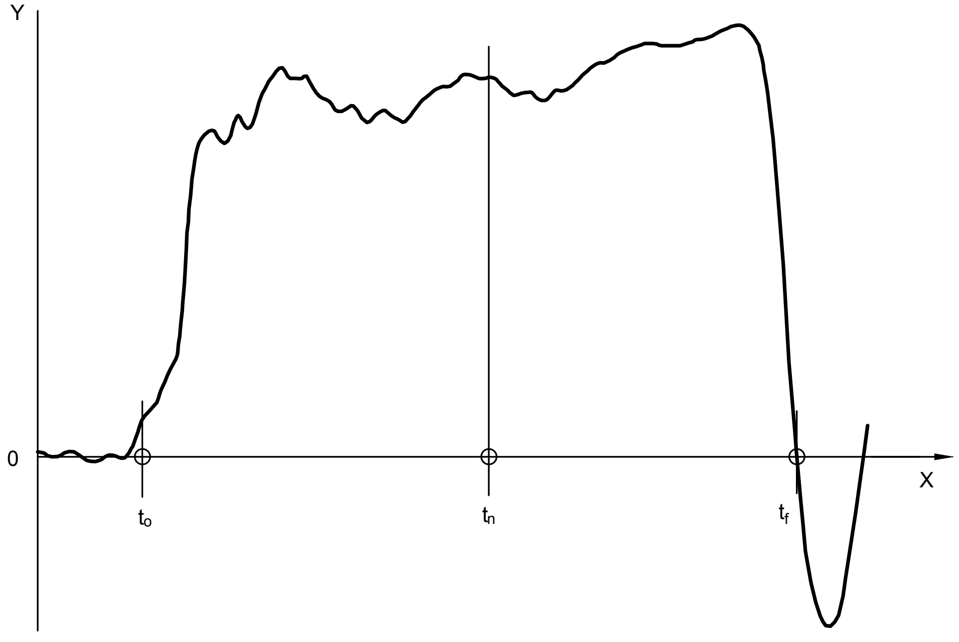
The reference point in time, t_0, for the following characteristic values is the moment of the brake-pedal actuation.

8.7.4.7.5 *Definition of times and requirements for standard evaluation*

Figure 10 shows the pattern of longitudinal acceleration during braking *versus* time.

For the correct performance of a test run, the rise time of the longitudinal acceleration shall not exceed 0.4 s. The longitudinal acceleration at 1 s after time t_0 is evaluated by taking the mean value during the time interval 0.9 s to 1.1 s after t_0. The rise time is defined as the difference between the reference point in time t_0 and time $t90$. Time $t90$ is the time when the longitudinal acceleration reaches 90 percent of the value at 1 s after time t_0.

The time tf is defined as the time when the longitudinal acceleration reaches the value zero at the end of the braking actuation.



X time, t
y longitudinal acceleration, - ax

FIG. 10 LONGITUDINAL ACCELERATION, $\overline{a}X$, *VERSUS* TIME

8.7.4.7.6 *Mean longitudinal acceleration*, − *a X*

The mean longitudinal acceleration is the average value of longitudinal acceleration measured during each brake application.

This average value may be obtained by either of the following methods:

a) measuring the distance needed by the vehicle to stop from instant *t*0, in which case the mean longitudinal acceleration is given by:

$$-\bar{a}_X = \frac{v_{\text{eff}}^2}{2\times s_{\text{eff}}}$$

where,

s_{eff} = The actual stopping distance, in metres;

v_{eff} = The actual initial velocity, in metres per second;

b) taking the mean value of the longitudinal acceleration during the time interval t_0 to t_f (*see* Fig. 10).

The method used to determine the mean longitudinal acceleration shall be recorded as the test conditions contained in Annex B of IS 17128 (Part 1).

8.7.4.7.7 *Mean longitudinal acceleration, Ax, Tn, until time tn*

The mean longitudinal acceleration at any time t_n after brake application is defined as the value during the time interval t_0 to t_n of the longitudinal acceleration (*see* Fig.10).

8.7.4.7.8 *Evaluation of characteristic values*

a) The characteristic values shall be determined and presented as a function of the mean longitudinal acceleration or the mean longitudinal acceleration at time t_n (*see* **8.7.4.7.6** and **8.7.4.7.7**). The characteristic values in the steady-state condition are defined as mean values during the time interval -1.3 s to -0.3 s before brake application. The other characteristic values are determined during an observation period beginning at t_0 and ending with the standstill of the vehicle. The representative values at t_n shall be calculated by taking the mean value during the time interval t_n – 0.1 s to + 0.1 s. For standard evaluation, the recommended value of time is $t_n = t_0 + 1$ s, but t_n may also assume additional values. If values for t_n in addition to t_0 + 1 s are chosen for evaluation of the characteristic values, the values of t_n shall be recorded on the plots of the characteristic values (*see* Annex A).

For each set of initial conditions, calculate and plot the characteristic values listed below. The reference values of yaw velocity and lateral acceleration used in some of the formulas are those values which would be obtained at time *t* and longitudinal velocity v_X, *t*, had the initial radius R_0 been maintained by the vehicle. They are defined as follows:

Reference yaw velocity:

$$\dot{\psi}_{\text{Ref},\,t} = \frac{v_{X,\,t}}{R_0}$$

Reference lateral acceleration:

$$a_{Y,\,\text{Ref},\,t} = \frac{v_{X,\,t}^2}{R_0}$$

b) *Lateral acceleration*

Steady-state levels of lateral acceleration in case of method 1), or centripetal acceleration in case of methods 2), 3) and 4), may be obtained by any one of the following four methods:

1) The output of an accelerometer, corrected for vehicle roll angle and for the distance of the sensor from the origin of the reference system.
2) The product of the yaw velocity, corrected for vehicle roll angle, and the longitudinal velocity, corrected for sideslip angle.
3) The square of the longitudinal velocity, corrected for sideslip angle, divided by the path radius.
4) The product of the square of the yaw velocity, corrected for vehicle roll angle, and the path radius.

The method used to determine lateral acceleration shall be noted in the test report.

c) The ratio of the value of the yaw velocity at time t_n to the value of the reference yaw velocity at time t_n (*see* Fig. 35):

$$\frac{\dot{\psi} t_n}{\dot{\psi}_{\text{Ref},\,t_n}} = f_1(-\bar{a}_{X,\,t_n})$$

d) The ratio of the maximum value of the yaw velocity attained during braking to the reference value of the yaw velocity at time $t_{\max}$, the instant when the maximum value of the yaw velocity is reached (*see* Fig.36):

$$\frac{\dot{\psi}_{\max}}{\dot{\psi}_{\text{Ref},\,t_{\max}}} = f_2(-\bar{a}_X)$$

e) The difference between the values of the instantaneous yaw velocity at time t_n and the reference yaw velocity at time t_n (*see* Fig. 37):

$$\Delta\dot{\psi} t_n = \dot{\psi} t_n - \dot{\psi}_{\text{Ref},\,t_n} = \dot{\psi} t_n - \frac{v_{X,\,t_n}}{R_0} = f_3(-\bar{a}_{X,\,t_n})$$

f) The maximum value of the difference between the yaw velocity during braking and the affiliated reference yaw velocity (*see* Fig. 38):

$$\Delta\dot{\psi}_{\max} = [\dot{\psi}_{t} - \dot{\psi}_{\text{Ref},\,t}]_{\max} = \left[\dot{\psi}\,t - \frac{v_{X,\,t}}{R_0}\right]_{\max} = f_4(-\bar{a}_X)$$

g) The instantaneous value of the yaw acceleration at time *t*n. The yaw acceleration may be computed by differentiating the yaw velocity (*see* Fig. 39):

$$\Delta\ddot{\psi}_{t_\text{n}} = \left.\frac{d\dot{\psi}}{dt}\right|_{t_\text{n}} = f_5(-\bar{a}_{X,\,t_\text{n}})$$

h) The ratio of the value of the lateral acceleration at time t_n to the reference value of the lateral acceleration at time t_n (*see* Fig.40):

$$\frac{a_{Y,\,t_\text{n}}}{a_{Y,\,\text{Ref},\,t_\text{n}}} = \frac{R_0}{R_{t_\text{n}}} = f_6(-\bar{a}_{X,\,t_\text{n}})$$

j) The maximum value of the sideslip angle during observation period and the time *t*bm (Beta-Max), expressing the time passed after t_0 until the maximum was reached (*see* Fig. 41):

$$\beta_{\max}\Big|_{t_0}^{t} = f_{7-1}(-\bar{a}_X)$$

$$t_{\text{bm}} = f_{7-2}(-\bar{a}_X)$$

k) he difference between the values of the sideslip angle at time t_n and the initial steady-state value of the sideslip angle (*see* Fig.42):

$$\beta_{t_\text{n}} - \beta_0 = f_8(-\bar{a}_{X,\,t_\text{n}})$$

m) The difference between the values of the instantaneous yaw velocity at time t_n and the calculated yaw velocity at time t_n (*see* Fig. 43):

$$\dot{\beta}'_{t_\text{n}} = \dot{\psi}_{t_\text{n}} - \frac{a_{Y,\,t_\text{n}}}{v_{X,\,t_\text{n}}} = f_9(-\bar{a}_{X,\,t_\text{n}})$$

where β′ is the sideslip angle velocity uncorrected for the effects of the sideslip angle itself and the deceleration. It gives information on the vehicle's yaw stability.

n) The path deviation at time t_n, defined as the radial distance of the reference point and its initial circular path (*see* Fig.44):

$$\Delta s_{Y,\,t_\text{n}} = f_{10}(-\bar{a}_{X,\,t_\text{n}})$$

The path deviation is calculated by the path of the reference point in the earth fixed axis system (*see* Fig. 11).The coordinates of the reference point can be determined for example by transforming the vehicle fixed velocity vectors $v^{\rightarrow}X$ and $v^{\rightarrow}Y$ into the earth fixed axis system and subsequent integration.

8.8 Method 4 — Quantification of on Centre Handling

8.8.1 *On-Centre Handling Weave Test*

8.8.1.1 *Description*

On-centre handling represents that part of the straight-line directional stability characteristics of the vehicle existing at lateral acceleration levels, typically, no greater than 1 m/s^2. On-centre handling is concerned primarily with features that directly influence the driver's steering input, such as steering system and tyre characteristics. Thus test schedules for the evaluation of on-centre handling behaviour seek to minimize other factors that influence the wider aspects of straight-line directional stability, such as disturbance inputs due to ambient winds and road irregularities.

This part defines a test schedule that involves driving the vehicle in a nominally straight line at a constant forward speed. During the test, driver inputs and vehicle responses are measured and recorded. From the recorded signals, characteristic values are calculated.

8.8.1.2 *Variables*

When using this test method, the following variables shall be measured in addition to the variables given in the Tables 5 and 6.

a) steering-wheel angle, δ_H;

b) steering-wheel torque, M_H;

c) yaw velocity, $\frac{\text{d}\psi}{\text{d}t}$; and

d) longitudinal velocity, v_X.

The following variables should be measured:

a) leteral acceleration, a_Y; and

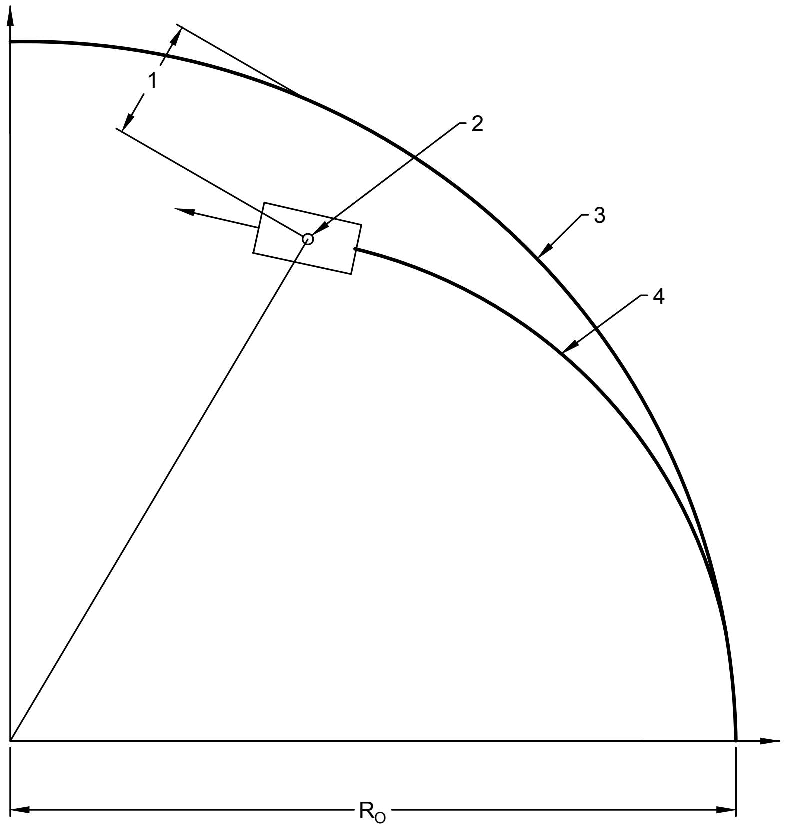
b) steering-wheel angular velocity, $\frac{\text{d}\delta_H}{\text{d}t}$.

8.8.1.3 *Test procedure — Weave test*

The weave test is an open-loop procedure conducted on a test track that follows a straight-line path. The vehicle is driven at a nominally constant longitudinal velocity. Different longitudinal velocities can be arrived based on vehicle capability. The standard test velocity is 100 km/h. These should be decremented or incremented by 20 km/h from the standard velocity.

The transducer signals shall be recorded throughout the initial driving condition, if applicable, and for the duration of the test. In order to ensure that the required data are not affected by the instrumentation system, recording should be continued for a further 1s after the test runs.

The weave test procedure requires the steering-wheel to be subjected to an oscillatory input. The preferred steering input waveform is nominally sinusoidal,



key
1 path deviation
2 vehicle referenced point
3 initial circular path
4 path of reference point

R_O initial radius

FIG. 11 DEFINITION OF PATH DEVIATION

Table 5 Variables, Typical Operating Ranges and Recommended Maximum Errors

(*Clause* 8.8.1.2)

Sl No. (1)	Variable (2)	Typical Operating Range[1] (3)	Recommended Maximum Error of Combined System[2] (4)
i)	Steering-wheel angle	± 50	± 0.1°
ii)	Steering-wheel torque	± 0,1 N - m	± 0.1 N. m
iii)	Yaw velocity	± 10 °/s	± 0.1 °/s
iv)	Longitudinal velocity	0 m/s to 50 m/s	± 0.5 m/s
v)	Lateral acceleration	± 5 m/s^2	± 0.1 m/s^2
vi)	Steering wheel angular velocity	± 100 °/s	± 1 °/s

Transducers for measuring some of the listed variable are not widely available and are not in general use. Many such instruments are developed by users. If any system error exceeds the recommended maximum value, this and the actual maximum error shall be stated in the test report (see ISO 15037-1, Annex A).

[1] These transducer ranges are appropriate for the standard test conditions and might not be suitable for non-standard test conditions.

[2] The values for maximum errors are provisional until more experience and data are available.

Table 6 Estimation Scale for Wind Intensity for Observer without Measuring Instrument (Beaufort Scale)

(*Clause* 8.8.1.2)

Wind intensity (Beaufort Scale)	**0**	**1**	**2**	**3**	**4**
Name	Calm	Light air	Light breeze	Gentle breeze	Moderate breeze
Velocity m/s	0 to 0.2	0.3 to 1.5	1.6 to 3.3	3.4 to 5.4	5.5 to 7.9
Identification Sign	Smoke rises vertically in a straight line	Wind direction only by smoke	Leaves rustle, Wind felt in face	Leaves and thin twigs move	Moves twigs and thin branches, dust rises

but other steering input waveforms (for example, triangular) may be used. The frequency of the steering input shall be 0.2 Hz ±10 percent. The amplitude of the steering input shall be sufficient to produce the required peak value of vehicle lateral acceleration ± 10 percent. To ensure that good and adequate test data are available for analysis at lateral acceleration levels of 1 m/s^2 and that the vehicle and its subsystems are working outside of hysteresis effects, the standard peak value is 2 m/s^2, but lower values and values up to 4 m/s^2 may also be used.

Throughout the test, both the peak amplitude of the steering angle and the angular velocity of the steering wheel through the centre position shall be as near constant as possible. In addition, variation in the position of the accelerator pedal shall be kept to a minimum, consistent with maintaining vehicle longitudinal velocity within required limits. The longitudinal velocity during the test sequence or sequences to be used for data analysis shall not vary from the nominal value by more than 3 percent. Choice of data used for analysis is based upon consistency of steering input and of vehicle longitudinal velocity relevant to that data. A minimum of four consistent cycles of steering input and of vehicle response is required for subsequent data analysis.

The steering input for this test may be made manually or with a steering robot machine. Where manual input is used, in order to obtain the minimum number of cycles required for analysis the test should be performed for a minimum continuous duration of 40 s, sufficient to capture at least eight cycles of data. Where proving ground space limitations prohibit a run of this duration, and consequently the reliable capture of a sufficiently long sequence of consistent data, it is permissible to perform a series of shorter runs and to combine the data for analysis. In this event, a nominal 20 cycles of data should be captured and statistical methods used during analysis. The use of a steering robot offers the possibility of enhanced consistency of steering input and hence of test data, allowing fewer test cycles.

8.8.1.4 *Data analysis and presentation of results*

8.8.1.4.1 *Time histories*

Time histories serve to monitor correct test performance and functioning of the transducers. In particular, the time histories of steering angle amplitude, steering-wheel angular velocity, vehicle longitudinal velocity and vehicle lateral acceleration are examined to identify valid data for evaluation. A minimum of four consistent cycles, for which the control criteria are best met, shall be selected for data analysis. Time histories of the variables listed in **5** shall be presented for the data selected for analysis.

8.8.1.4.2 *Calculated lateral acceleration*

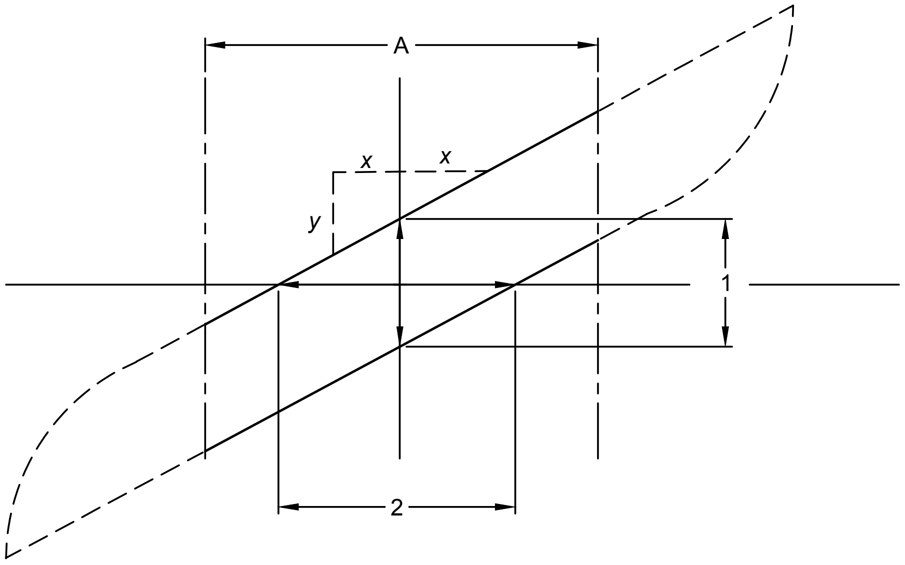
Instead of using measured lateral acceleration, aY, in the derivation of several of the characteristic values identified in **9.4**, the parameter "calculated lateral acceleration" may be used. Calculated lateral acceleration, aYc, is calculated as the product of yaw velocity, dΨ/dt (in radians per second) and longitudinal velocity, vX, and is expressed in units of metres per second squared:

$$a_{Yc} - \frac{\mathrm{d}\psi}{\mathrm{d}t} v_X$$

8.8.1.4.3 *Characteristic values*

The recorded variables are taken in pairs and plotted one against the other on Cartesian co-ordinates. For each pair of variables, this produces a series of hysteresis loops laid one over another, the number of loops corresponding to the number of data cycles analyzed.

The hysteresis loops should be "averaged" by some suitable method. The recommended method is to make a polynomial curve fit to the combined data over the range A for each of the upper and lower sides of the combined hysteresis loops, where, A is an appropriate percentage of the peak-to-peak abscissa range of the data (*see* Fig. 1). The recommended order for the polynomial curve fit is 3, and the recommended value for A is between 50 per cent and 70 per cent. The value



gradient = $\frac{y}{2x}$

Key

1 ordinate deadband
2 abscissa deadband
A range of polynomial curve fit

Fig. 12 Definition of Parameters

chosen for A should be sufficiently large to adequately cover the range of data of interest, but sufficiently restrictive to avoid end effects from the limits of the loops.

The recommended method for evaluating a gradient is to make a best straight line fit to the polynomial in the region of interest. For an average gradient this would be over a specified range (as detailed below), and for an "instantaneous" gradient this would be over a small interval around the point of interest, typically the size of the interval would correspond to that defined by a lateral acceleration of 0.1 m/s^2.

Other methods may be employed for analysing and averaging the data. For example, straight line rather than polynomial curve fitting may be used. Each hysteresis loop may be analysed individually and the characteristic parameters, yielded from all the loops averaged to obtain overall results.

The actual procedures and details used will depend upon the analysis software package employed and the nature of the data, and shall be stated in the test report.

From the polynomial curve fits to the combined hysteresis loops, the following parameters are evaluated:

a) ordinate deadband;
b) abscissa deadband; and
c) gradient.

The pairs of variables to be plotted (ordinate given first) and the characteristics that can be evaluated are :

a) **Steering-wheel torque *versus* steering-wheel angle** (M_H Vs δ_H)

Steering stiffness: average gradient over range ± χ°, where χ = 10 percent of peak steering angle.

Steering stiffness at zero steer: gradient evaluated at zero steering angle.

Steering friction: ordinate dead band.

Angle hysteresis: abscissa dead band.

b) **Yaw velocity *versus* steering-wheel angle (dψ/dt Vs δ_H)**

Yaw velocity response gain: average gradient over range ± χ°, where χ = 20 percent of peak steering angle.

Yaw velocity time delay: time delay of yaw velocity with respect to steering angle input.

c) **Yaw velocity *versus* steering-wheel torque** (dψ/dt Vs M_H)

Response dead band: abscissa deadband.

d) **Lateral acceleration *versus* steering-wheel angle** (a_Y Vs δ_H)

Steering sensitivity: average gradient over range ± χ°, where χ = 20 percent of peak steering angle.

Minimum steering sensitivity: minimum instantaneous gradient evaluated within range ± 1 m/s^2.

Steering sensitivity at 1 m/s^2: gradient evaluated at 1m/s^2 while steering away from centre.

Lateral acceleration deadband: ordinate deadband.

Angle deadband: abscissa deadband.

Steering hysteresis: area bounded by hysteresis loop and ordinate values 1 m/s^2, divided by 2 m/s^2 (equivalent to average angle deadband).

Lateral acceleration time delay: time delay of lateral acceleration with respect to steering angle input.

NOTE — The evaluation of lateral acceleration time delay is invalid where lateral acceleration is calculated rather than measured.

e) **Steering-wheel torque *versus* lateral acceleration** (M_H Vs a_y)

Torque at 0 m/s^2: ± torque levels at zero m/s$^{2.}$

Torque at 1 m/s^2: ± torque levels at ± 1 m/s^2 while steering away from centre.

Lateral acceleration at 0 N m: ± lateral acceleration levels at 0 N.m.

Torque gradient at 0 m/s^2: gradient evaluated at 0 m/s^2.

Torque gradient at 1 m/s^2: gradient evaluated 1m/s^2 while steering away from centre.

Torque hysteresis: ordinate deadband.

Lateral acceleration hysteresis: abscissa deadband.

8.8.2 *On-Centre Handling Transition Test*

8.8.2.1 *Transition Test Procedure*

The transition test is an open-loop procedure and is conducted from an initial straight-line path. The vehicle is driven at a nominally constant longitudinal velocity. Different longitudinal velocities can be arrived based on vehicle capability. The standard test velocity is 100 km/h. These should be decremented or incremented by 20 km/h from the standard velocity.

Details shall be recorded in the test report. The transducer signals shall be recorded throughout the initial driving condition and for the duration of the test; to ensure that the required data are not affected by the instrumentation system, it is recommended to continue recording for a further 1s after the test run.

Whereas the weave test examines the outer edge of the response hysteresis loop, this test examines the transition from straight line running to the edge of the hysteresis loop.

Continuing from the initial driving condition specified in **8.2**, the steering-wheel shall be subjected to a ramp input (that is one that increases in amplitude with a nominally constant angular velocity). To ensure a smooth transition of the vehicle path from the straight-ahead condition onto a curve of diminishing radius, the steering input shall be applied with an angular velocity that increases smoothly from zero up to the nominally constant value. Commencing at time t_0, the steering input shall be applied for a minimum duration of 3 seconds, and at an angular velocity not exceeding 5 degrees/second, until the lateral acceleration achieved by the vehicle reaches a minimum of 1,5 m/s^2. The test shall be performed a sufficient number of times in each turn direction using, nominally, the same steer input profile.

Details of the steering input, angular velocity and duration of application shall be recorded in the test report. The longitudinal velocity during the test runs to be used for data analysis shall not vary from the nominal value

8.8.2.2 *Data analysis and presentation of results*

Data analysis and presentation of results shall be as specified in **8.8.1.4**.

On each Cartesian plot, a separate best straight-line fit is made to the data for each turn direction (*see* Fig. 13). Each straight-line fit should exclude either data that is severely non-linear, such as that in the on-centre region (typically that obtained in the lateral acceleration range ± 0.5 m/s^2), or data obtained at lateral accelerations in excess of ± 1.2 m/s^2. The data range that is used to make each straight-line fit shall be recorded in the test report (*see* ISO 15037-1, Annex B).

NOTE — The upper bound of ± 1.2 m/s^2 is advisory. If linear characteristics are not apparent at lateral accelerations below this value, then an alternative data range may be chosen following prudent examination of the characteristic shape.

8.9 Method 5 — Free Steer Behaviour

8.9.1 *Steering Release — Description*

This test is intended for evaluating the ability of a vehicle to return to a straight path following steering-wheel release from a steady-state turn.

The initial conditions are defined by a steady-state circular motion. During the test, the driver releases the steering wheel. The steering-wheel angle and the vehicle response are measured and recorded. From the recorded signals, characteristic values are calculated.

8.9.2 *Variables*

Measure the following variables (*see* Table 7):

a) Longitudinal velocity (v_X);

b) Lateral acceleration (a_y);

c) Yaw velocity (ψ); and

d) Steering-wheel angle (δ_H).

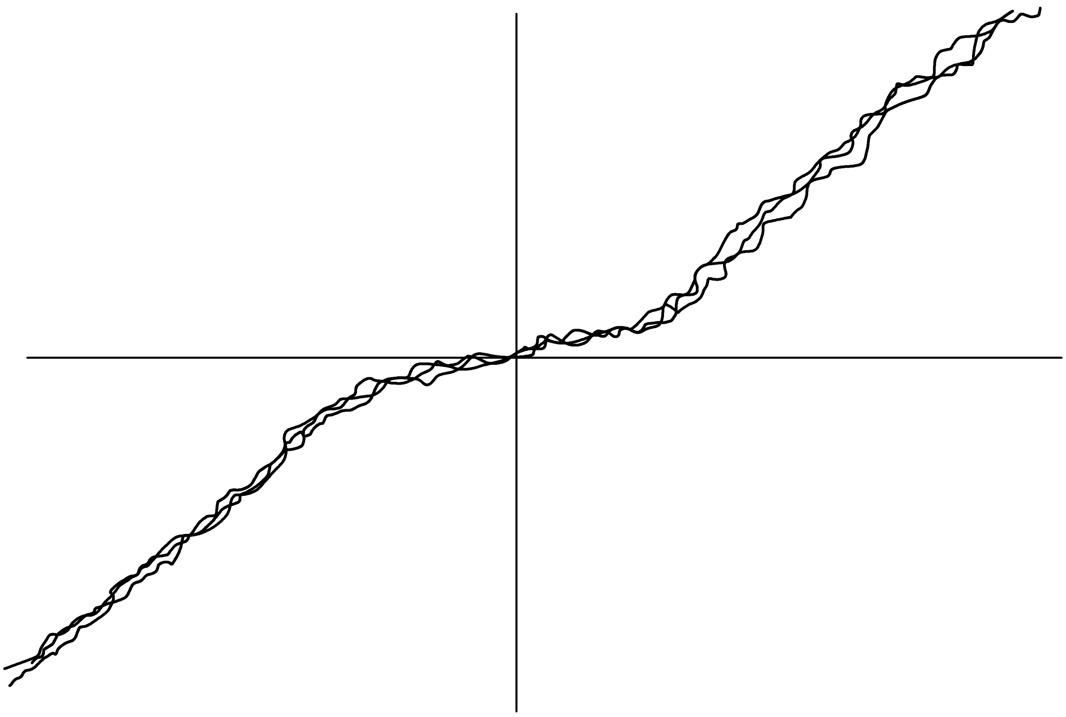
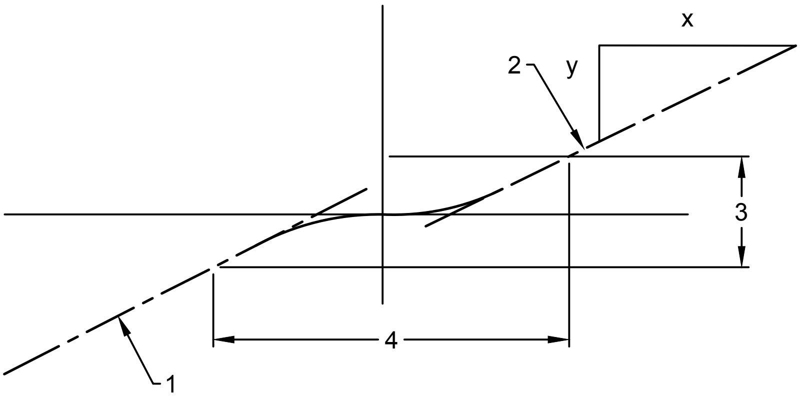


Fig. 13 Cartesian Plots of Data Obtained from Several Test Runs



Key
1 straight-line fit to right-turn data
2 straight-line fit to right-turn data
3 ordinate threshold
4 abscissa deadband

gradient = y/x

Fig. 14 Definition of Parameters

Table 7 Variables, Typical Operating Ranges and Recommended Maximum Errors

(*Clause* 8.9.2)

Sl No. (1)	Variable (2)	Typical Operating Range (3)	Recommended Maximum Error of Combined transducer-recorder system (4)
i)	Longitudinal velocity	0 m/s to + 50 m/s	± 0.3 m/s
ii)	Lateral acceleration	-15 m/s^2 to + 15 m/s^2	± 0.1 m/s^2
iii)	Yaw velocity	-50°/s to +50°/s	± 0.3°/s
iv)	Steering-wheel angle	-360° to + 360°	± 2° for $|\delta H| \leq 180°$ ± 4°, otherwise

8.9.3 *Test Procedure*

The starting condition for the test is a steady-state circular motion at a prescribed level of lateral acceleration, aY_0.

The steady-state circular motion shall be in accordance with IS 17128 (Part 1), except for the following:

a) for the time interval from t_1 to t_2, the standard deviation of the lateral acceleration shall not exceed 3 percent of its mean value or 0.2 m/s^2, whichever is the higher.

b) The standard longitudinal velocity shall be 100 km/h, it may vary by steps of 20 km/h.

c) Where possible, the test should be conducted performing alternating left and right turns. The initial prescribed level of lateral acceleration aY_0 of 1 m/s^2 shall be incremented in steps of, nominally, 1 m/s^2, until a limiting condition is reached.

d) From each starting condition, the driver shall suddenly release the steering wheel at the reference point in time, t_0 while maintaining the throttle constant and placing the vehicle in free control, so that its response is determined by its dynamic characteristics.

e) Record test data from time t_1 for 1 s after the steering oscillation is completely damped or until t_0 = 5 s, whichever is the shorter.

f) The test should be repeated from starting conditions at incremented levels of lateral acceleration until vehicle response becomes divergent, or the limit of lateral adhesion is reached in the starting condition.

NOTE — It is recommended that the steering-wheel angle be measured using transducers in conjunction with the original steering wheel of the vehicle. Alternatively, a replacement instrumented steering wheel may be used. In either event, care should be taken to avoid changing the mass centre, inertial properties or friction of the steering system.

8.9.4 *Data Analysis*

8.9.4.1 Ratio between second and first peak of a given variable after steering-wheel release.

For each of the variables (*see* Fig. 15) namely, Side slip angular velocity, Yaw velocity and steering-wheel angle:

a) evaluate the function *f*(a y0) = peak 2/peak 1, at each level of initial lateral acceleration ay0;

b) plot the function *f*(a y0) vs ay0;

c) compute the linear regression (*see* Fig. 16);

d) calculate m, the slope of the linear regression; and

e) calculate q, the value of the linear regression at a lateral acceleration of 4 m/s^2.

NOTE — Sideslip angular velocity is usually calculated by the formula:

$$\beta(t) = \frac{a_y(t) - \psi(t)}{v_X(t)}$$

where,

a_y = Lateral acceleration of the vehicle;

v_X = Longitudinal velocity of the vehicle; and

ψ = yaw velocity of the vehicle.

8.9.4.2 *Value of second peak of a given variable after steering-wheel release*

For each of the variables (*see* Fig. 15), namely, side slip angular velocity, Yaw velocity and steering-wheel angle:

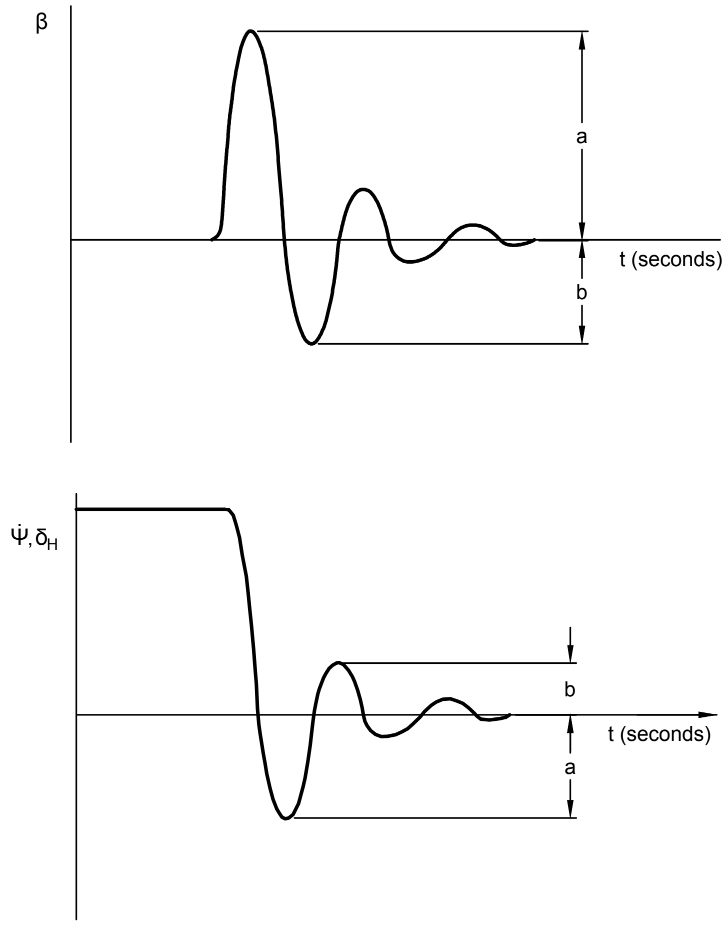
a) evaluate the function *f(a y0)* = peak 2, at each level of initial lateral acceleration ayo;

b) plot the function *f* (a y0) vs a y0;

c) compute the linear regression (*see* Fig. 16);

d) calculate m, the slope of the linear regression; and

e) calculate q, the value of the linear regression at a lateral acceleration of 4 m/s^2.



a. peak 1
b. peak 2

FIG. 15 PEAKS OF VARIABLES AFTER STEERING-WHEEL RELEASE

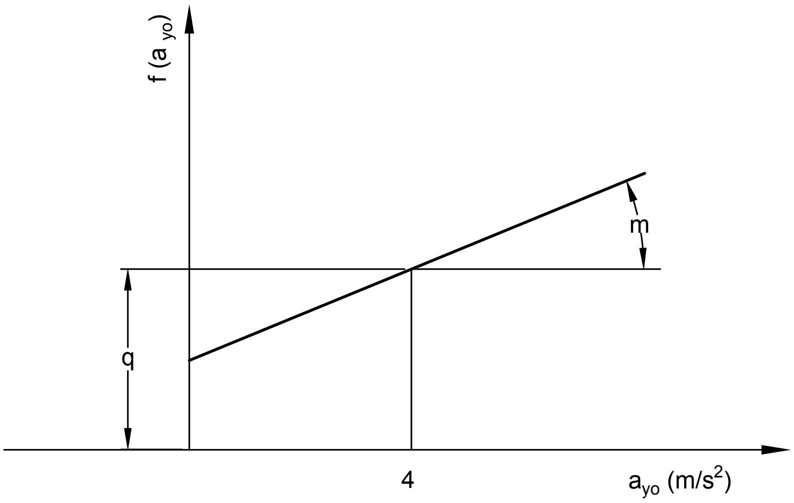


FIG. 16 TYPICAL ASPECT OF FUNCTIONS OF LATERAL ACCELERATION

8.9.4.3 *Delay of first peak of a given variable after t*50 (*see* Fig. 17)

For each of the variables (*see* Fig. 15)), namely, steering-wheel angle and lateral acceleration:

a) evaluate the function f(ay0) = time delay of peak 1, at each level of initial lateral acceleration ayo;

b) plot the function f (ay0) vs a y0;

c) compute the linear regression (*see* Fig. 16);

d) calculate m, the slope of the linear regression; and

e) calculate q, the value of the linear regression at a lateral acceleration of 4 m/s^2.

8.9.5 *Steering Pulse — Description*

This test is intended to evaluate the ability of the vehicle to return to a straight path following a steering pulse input from a straight ahead, steady state driving initial condition.

Oscillation of the vehicle is initiated by the application of a single pulse steering input. This is followed by release of the steering wheel and a period during which the steering wheel is free. The steering-wheel angle and the vehicle response are measured and recorded. From the recorded signals, characteristic values are calculated.

8.9.6 *Variables*

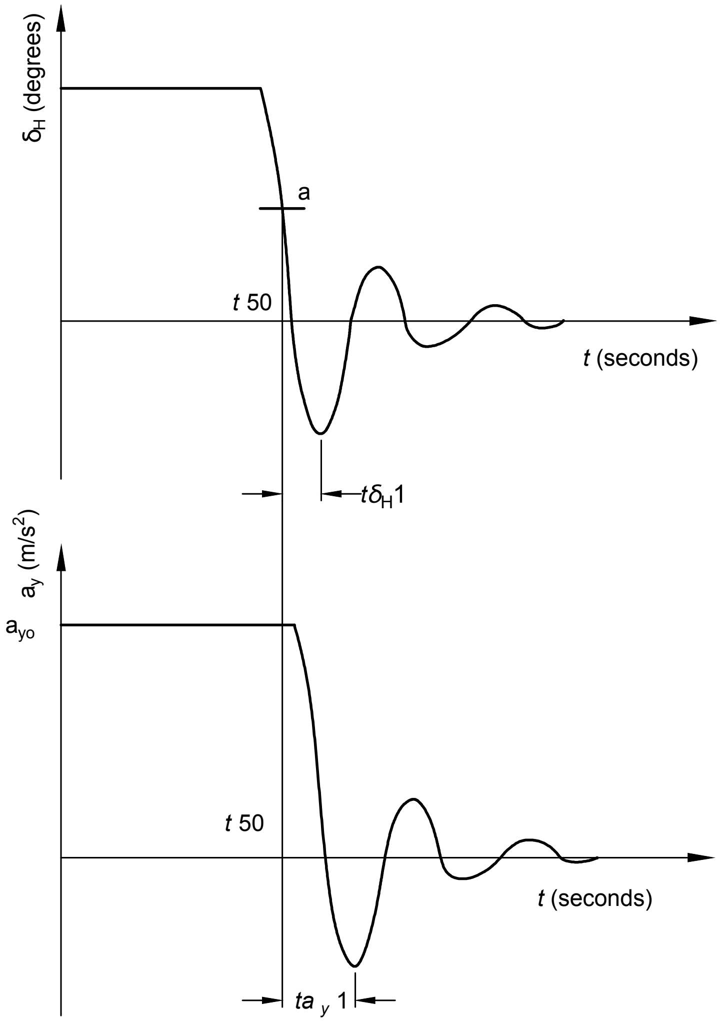
Measure the following variables (*see* Table 8)

a) longitudinal velocity (v_X);

b) lateral acceleration (a_Y);

c) yaw velocity (ψ); and

d) steering-wheel angle (δ_H).



a 50% of the initial level

Fig. 17 Delay of First Peak of Steering-Wheel Angle and Lateral Acceleration

8.9.7 *Test Procedure*

The starting condition, for the test is steady-state ahead running motion at a prescribed longitudinal velocity vx.

The test shall be conducted for a minimum of three longitudinal velocities. These shall include the standard longitudinal velocity of 100 kmph, and other velocities varied in steps of 20 kmph

From each starting condition, the driver shall apply the steering pulse input to a predetermined value and release the steering wheel immediately to place the vehicles in free control with its response determined by its dynamic characteristic. The throttle shall be maintained constant, even though velocity can decrease.

The test shall be conducted with an amplitude of steering wheel angle sufficient to produce the initial lateral acceleration (ay) of 1 m/s^2. The test shall be repeated with incremented amplitude on steering wheel angle peak, such that lateral acceleration is incremented in steps of not more than 0.5 m/s^2 up to a level of at least 5 m/s^2 (*see* Fig. 16 and Fig. 17).

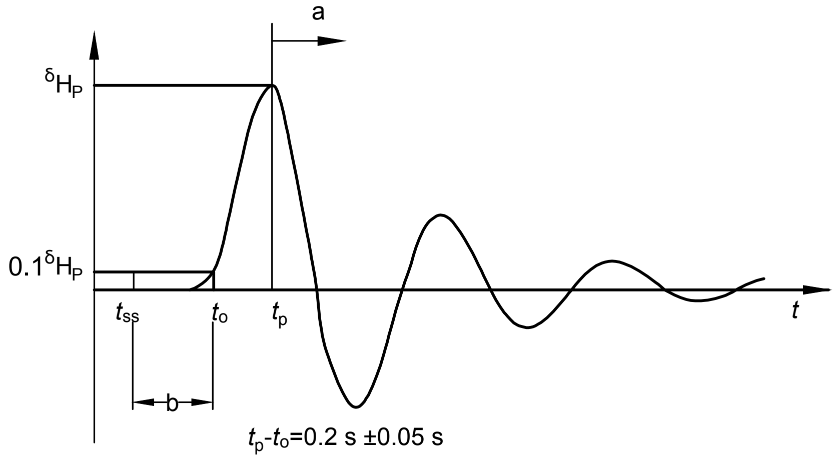
Referring to the example time history of steering wheel angle shown in Fig. 18, t_0 is the time in seconds and amplitude if steering wheel angle first exceeds 10 percent of its maximum amplitude, and tp is the time of maximum amplitude at which the steering wheel is released. The rise time of pulse input (t_p - t_0) shall be 0.2 s +/- 0.005 s. Test data are recorded from time t_{ss} - 0.5 s until 1 s after the steering oscillation is completely damped or until t_0 + 5s – whichever is shorter.

Where possible, test should be conducted in both left and right turning directions.

Table 8 Variables, Typical Operating Ranges and Recommended Maximum Errors

(*Clause* 8.9.6)

Sl No.	Variable	Typical Operating Range	Recommended Maximum Error of Combined Transducer-Recorder System
(1)	(2)	(3)	(4)
i)	Longitudinal velocity	0 m/s to + 50 m/s	± 0.3 m/s
ii)	Lateral acceleration	-15 m/s^2 to + 15 m/s^2	± 0.1 m/s^2
iii)	Yaw velocity	-50°/s to +50°/s	± 0.3°/s
iv)	Steering-wheel angle	-360° to + 360°	± 2° for l δ_H l ≤ 180° ± 4°, otherwise



KEY

t time δ

$^{\delta}H_P$ maximum amplitude of steering-wheel angle

a free steer control

b 0.5 s to 0.8 s

Fig. 18 Steering Wheel Angle Input

8.9.8 *Data Analysis*

The recorded time history of the following variables shall be displayed and examined visually. Result not considered to be representative shall be discarded:

a) Yaw velocity;
b) Steering-wheel angle; and
c) Sideslip angular velocity.

NOTE — Sideslip angular velocity is usually calculated by the formula:

$$\beta(t) = \frac{a_y\,(t)}{v_X\,(t)} - \dot{\psi}(t)$$

where,

v_X = Longitudinal velocity of the vehicle;
ψ = Yaw velocity of the vehicle; and
a_y = Lateral acceleration of the vehicle.

8.9.8.1 *Damping and damping time of yaw velocity*

Referring to the example time history of yaw velocity shown in Fig. 19, all amplitudes starting with the second peak shall be determined. Calculate the mean value of the amplitude rations, $\bar{\tau}$, using equation (2):

$$\bar{\tau}\ \frac{1}{n-2}\left\{\frac{\dot{\psi}_1+\dot{\psi}_2}{\dot{\psi}_2+\dot{\psi}_3}+\frac{\dot{\psi}_2+\dot{\psi}_3}{\dot{\psi}_3+\dot{\psi}_4}+\frac{\dot{\psi}_3+\dot{\psi}_4}{\dot{\psi}_4+\dot{\psi}_5}+\ldots+\frac{\dot{\psi}_{n-2}+\dot{\psi}_{n-1}}{\dot{\psi}_{n-1}+\dot{\psi}_n}\right\} \tag{2}$$

NOTE — Each amplitude, ψ_n. is an absolute value.

$\dot{\psi}_{n-1}+\dot{\psi}_n$ Shall be at least 10 percent of $\dot{\psi}_1+\dot{\psi}_2$ or $\dot{\psi}_n$ shall be the last amplitude of the recorded time period of 5 s.

When the amplitude of third peak, $\dot{\psi}_3$, is too small to be determined clearly, or $\dot{\psi}_2$ is smaller than 10 percent of $\dot{\psi}_1$, calculate $\bar{\tau}$ using Equation (3):

$$\bar{\tau}\ \frac{\dot{\psi}_1}{\dot{\psi}_2} \tag{3}$$

Calculate the damping of yaw velocity D, using equation (4):

$$D = \frac{In\,\bar{\tau}}{\sqrt{\pi^2+\left(In\,\bar{\tau}\right)^2}} \tag{4}$$

Calculate the damping time of yaw velocity, $T_{0.1}$ — which indicates the duration of yawing oscillation (for example, the time period required to decrease the yaw velocity within 10 percent level of peak 1) — using Equation (5):

$$T_{0.1} = \frac{In10}{D\times\omega} \tag{5}$$

where

$$\omega = \frac{\pi\left(n-1\right)}{t_n - t_1\sqrt{1-D^2}} \tag{6}$$

For each of the variables, namely, damping of yaw velocity and damping time of yaw velocity:

a) Evaluate the functions $f(a_{Y0})$ = D and $f(a_{Y0}) = T_{0.1}$, at each level of initial lateral acceleration a_{Y0}:
b) Plot the functions $f(a_{Y0})$ Vs a_{Y0};
c) Compute the linear regression between 3 m/s^2 and 5 m/s^2 (*see* Fig. 20 and 21);
d) Calculate *q*, the value of the linear regression at a lateral acceleration of 4 m/s^2;
e) Calculate *m*, the gradient of the linear regression, using:

$$m = (q_5 - q_3) / 2$$

f) Plot *q* and *m* Vs longitudinal velocity (*see* Fig. 22, 23, 24 and 25).

8.9.8.2 *Ratio between second and first peak of a given variable after steering wheel release*

This method of data analysis may be used when observed free control behavior is not oscillatory enough to calculate the damping.

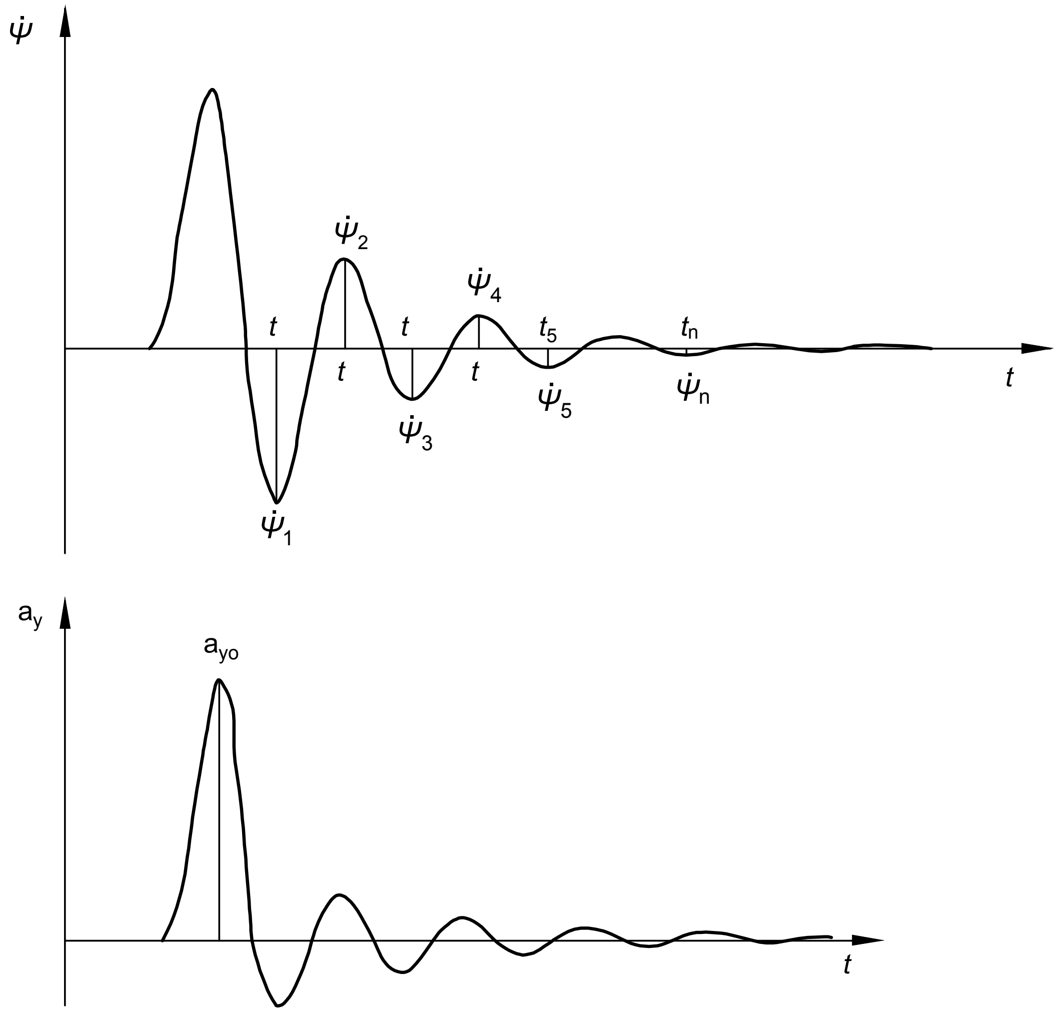
EXAMPLE — Test at low longitudinal velocity.

For each of the variables:

a) Yaw velocity,
b) Steering-wheel angle, and
c) Sideslip angular velocity, (*see* Fig. 26 and 27):
    1) Evaluate the function $f\,(a_{yo})$ = peak 2/peak 1, at each level of initial lateral acceleration a_{yo};
    2) Plot the function $f\,(a_{yo})$ vs a_{yo};
    3) Compute the linear regression between 3 m/s^2 and 5 m/s^2 (*see* Fig. 11);
    4) Calculate '*q*', the value of the linear regression at a lateral acceleration of 4 m/s^2;
    5) Calculate '*m*', the gradient of linear regression, using equation (8):

$$m = (q_5 - q_3) / 2 \tag{8}$$

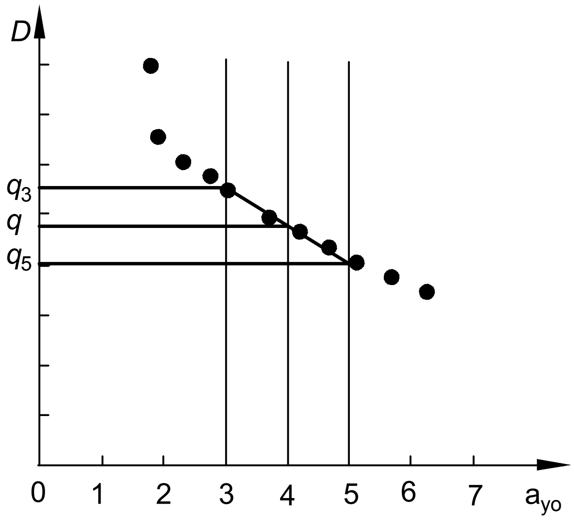
    6) Plot *q* and *m* vs longitudinal velocity (*see* Figures 29 and 30).



KEY

t	time δ
$\dot{\psi}$	yaw velocity
a_y	lateral acceleration

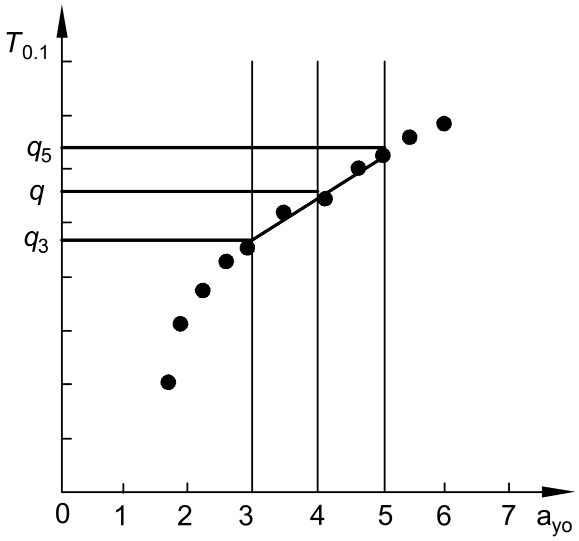
Fig. 19 Determination of Amplitude



KEY

a_{yo}	lateral acceleration m /s^2
D	damping time of yaw velocity
q	value of linear regression

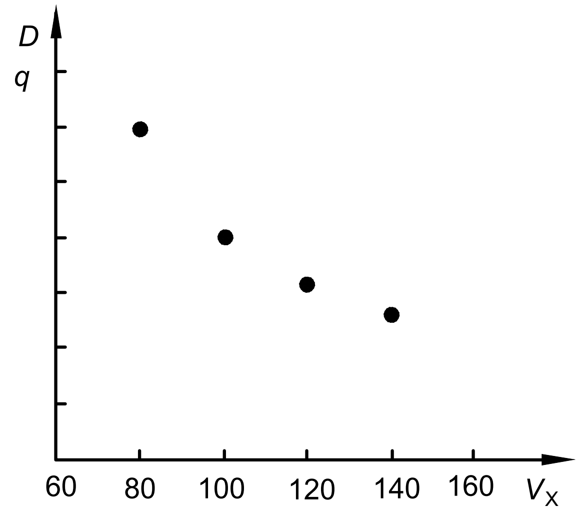
Fig. 20 Typical Aspect of Damping Time Vs a_{y0}



KEY

a_{yo}	lateral acceleration m/s^2
$T_{0.1}$	damping time of yaw velocity
q	value of linear regression

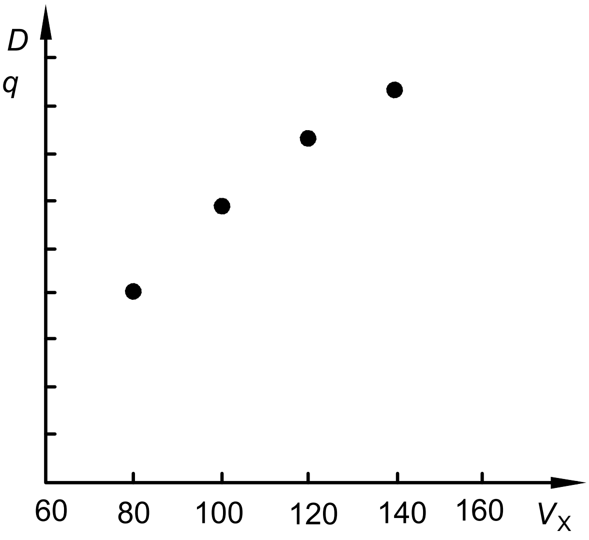
Fig. 21 Typical Aspect of Damping Time Vs a_{y0}



KEY

V_X	longitudinal acceleration, km/h
D	damping of yaw velocity
q	value of linear regression

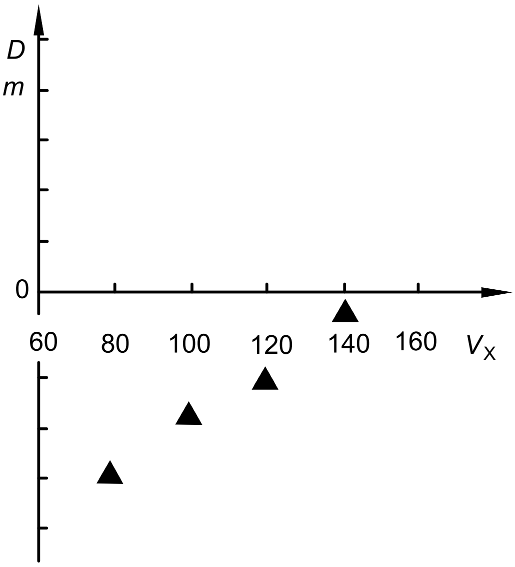
FIG. 22 q OF DAMPING VALUE VS LONGITUDINAL VELOCITY



KEY

V_X	longitudinal acceleration, km/h
$T_{0.1}$	damping time of yaw velocity
q	value of linear regression

FIG. 23 q OF DAMPING VALUE VS LONGITUDINAL VELOCITY



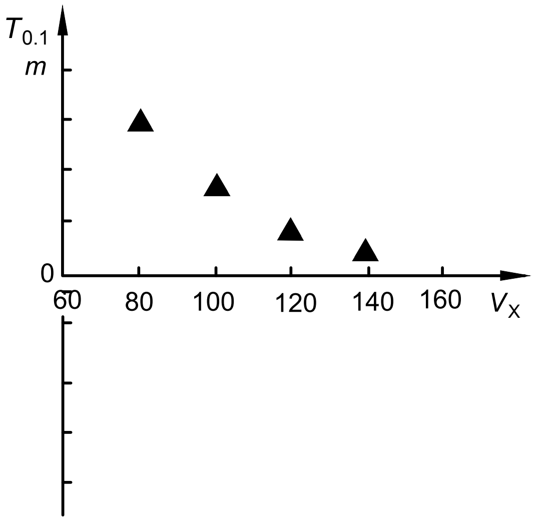
KEY

^{v}x longitudinal velocity km/h

D damping of yaw velocity

m gradient of linear regression

Fig. 24 m of Damping Value Vs Longitudinal Velocity



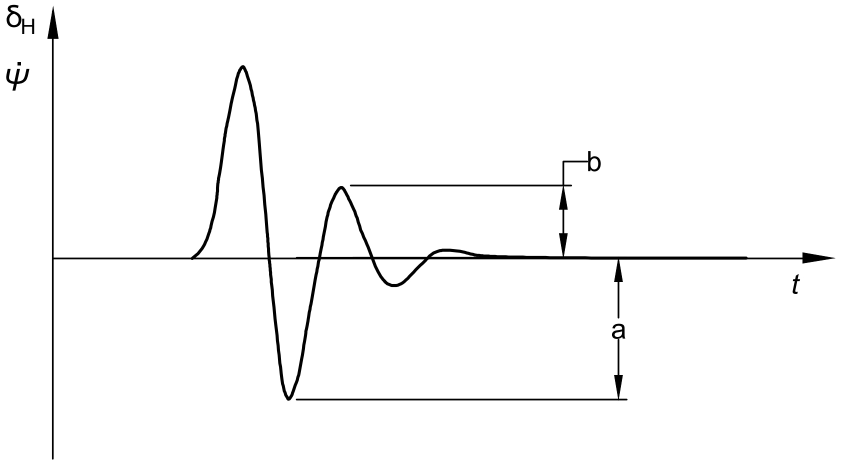
KEY

^{V}X longitudinal velocity km/h

$T_{0.1}$ damping time of yaw velocity

m gradient of linear regression

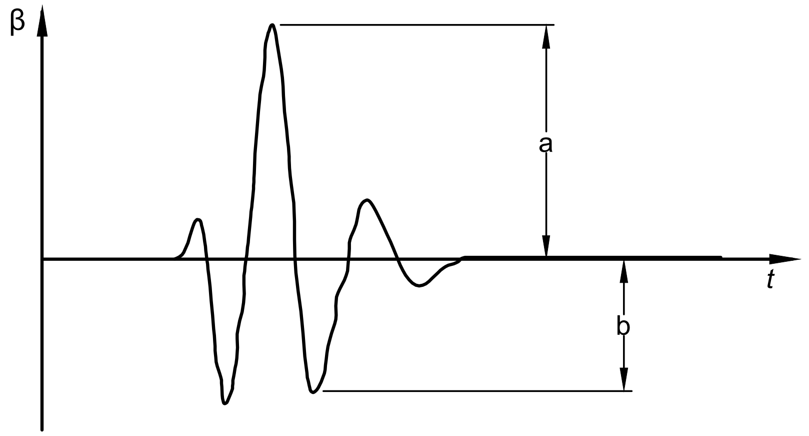
Fig. 25 m of Damping Value Vs Longitudinal Velocity



KEY

t	time s
$\dot{\psi}$	yaw velocity
δ_H	steering-wheel angle
a	peak 1
b	peak 2

FIG. 26 PEAKS OF VARIABLE AFTER STEERING-WHEEL RELEASE-STEERING - WHEEL ANGLE, YAW VELOCITY



KEY

t	time, s
β	sideslip angular, velocity
a	peak 1
b	peak 2

FIG. 27 PEAKS OF VARIABLE AFTER STEERING-WHEEL RELEASE-STEERING - SIDESLIP ANGULAR VELOCITY

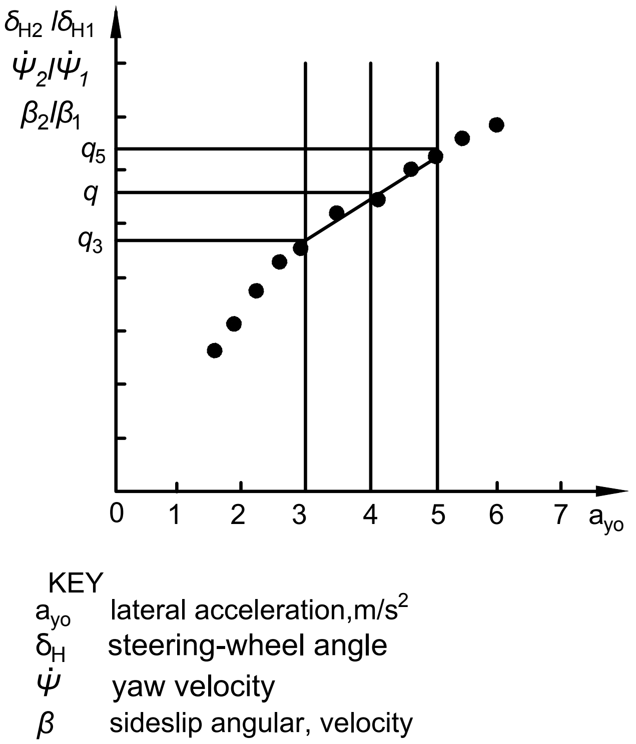


FIG. 28 TYPICAL ASPECT OF FUNCTIONS OF LATERAL ACCELERATION VS a_{y0}

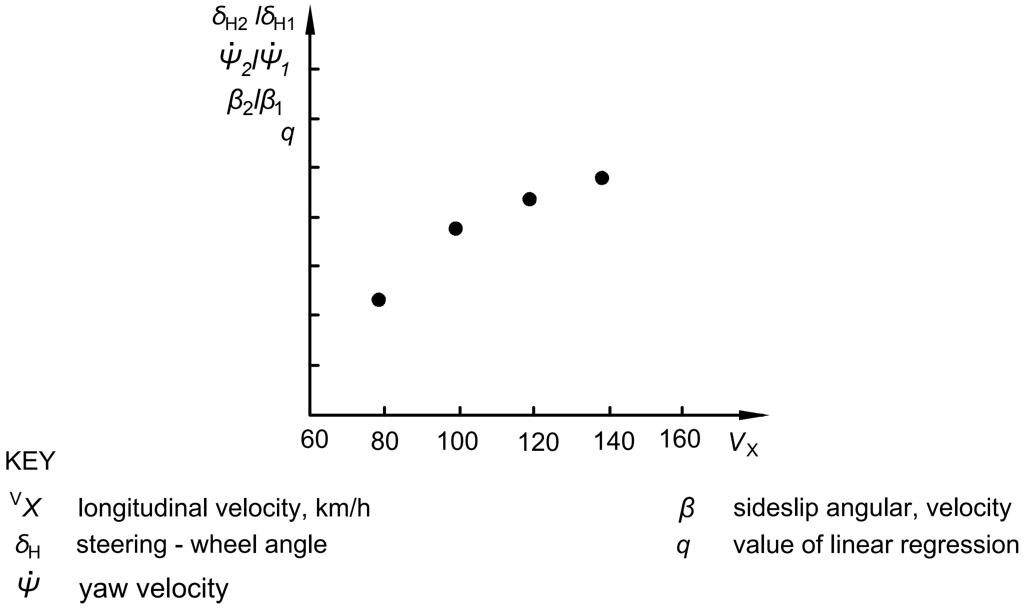
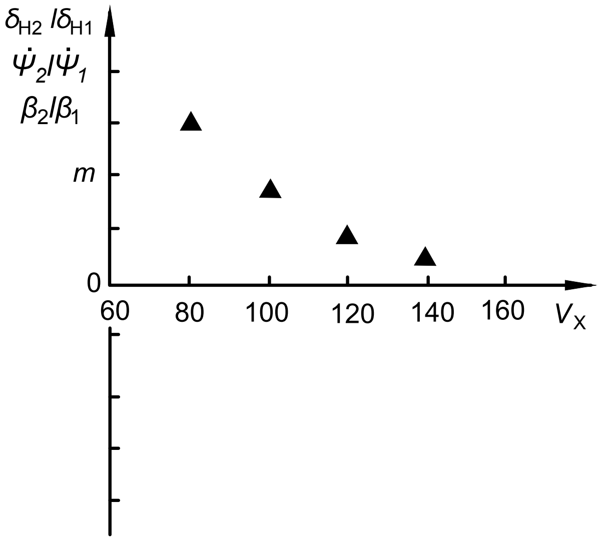


FIG. 29 q OF RATIO BETWEEN THE SECOND AND FIRST PEAK VS LONGITUDINAL VELOCITY-STEERING-WHEEL ANGLE, YAW VELOCITY, SIDESLIP ANGULAR VELOCITY



KEY

^{V}X	longitudinal velocity km/h
δ_H	steering-wheel angle
$\dot{\psi}$	yaw velocity
β	sideslip angular velocity
m	gradient of linear regression

FIG. 30 m OF RATIO BETWEEN THE SECOND AND FIRST PEAK VS LONGITUDINAL VELOCITY-STEERING-WHEEL ANGLE, YAW VELOCITY, SIDESLIP ANGULAR VELOCITY

ANNEX A

(*Normative*)

TEST REPORT: GENERAL DATA

A-1 VEHICLE IDENTIFICATION

a) Make, year, model, type:
b) Vehicle identification number:
c) Steering type:
d) Suspension type: Front Rear
e) Engine size, optical equipment:
f) Tyres: make, size, date, condition:
g) Tyre pressure: Front Rear
    1) Cold: kPa kPa
    2) Hot, after test (if measured): kPa kPa
h) Tyre tread depth: Front Rear
    1) Before test:\ mm mm
    2) After test: mm mm
j) Rims: Wheelbase:
k) Track: Front mm Rear mm
m) Overall steering ratio:
n) Other data (in particular, relevant Suspension settings):

A-2 VEHICLE LOADING

	Left	**Right**	**Sum**
a) Vehicle kerb mass:	Front : kg	Front: kg	kg
b) Vehicle kerb mass	Rear : kg	Rear: kg	kg
c) Loading condition and location**:**	**Left**	**Right**	**Sum**
	Front: kg	Front: kg	kg
	Rear: kg	Rear: kg	kg

A-3 TEST CONDITIONS

a) Test surface description:
b) Weather conditions:
c) Temperature :
d) Wind speed :
e) Test method chosen for evaluation (*see* "IMPORTANT", *Clause* **3**)
f) Time domain :
g) Frequency domain :

A-4 TEST PERSONNEL

a) Driver :
b) Observer :
c) Data analyst :

A-5 GENERAL COMMENTS:

ANNEX B

(*Normative*)

TEST REPORT : PRESENTATION OF RESULTS

B-1 STEP INPUT

Test number: …………………………….

v_x = 100 km/h |………………km/h

a_y = 4 m/s^2 | ………………m/s^2

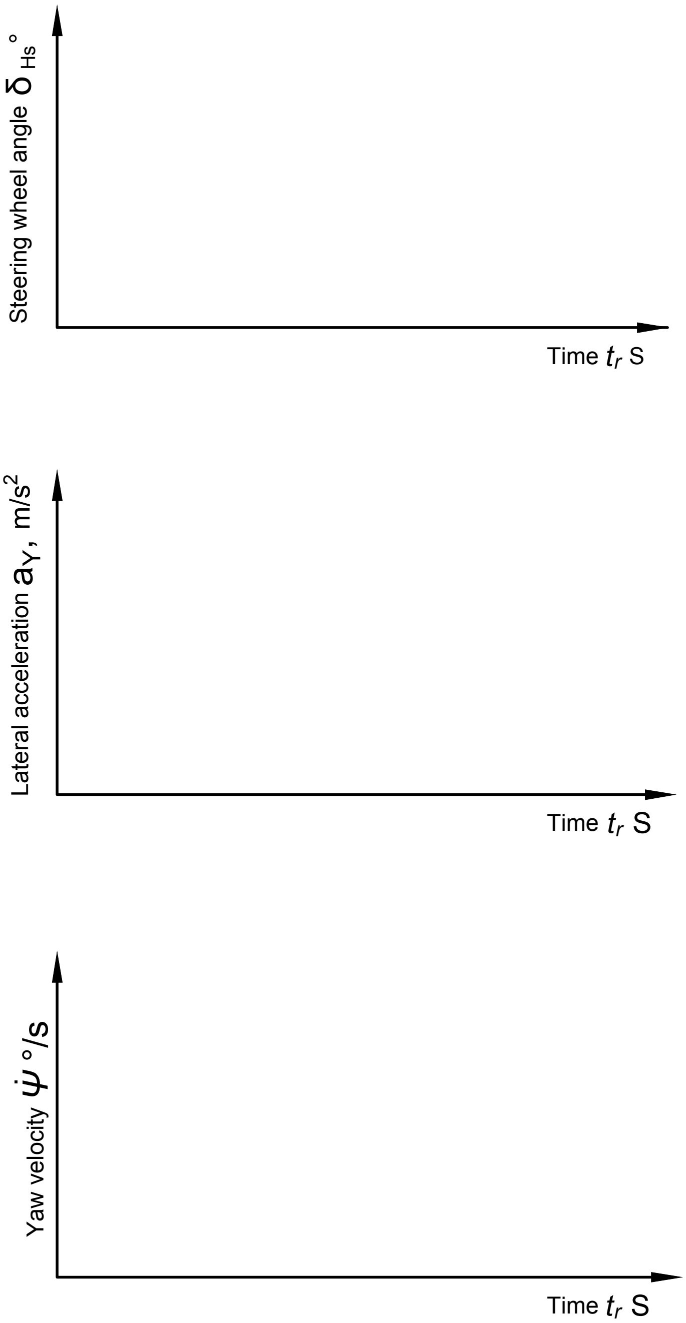


FIG. 31 STEP INPUT – TIME HISTORIES

Table 9 Step Input — Response Data Summary

(*Clause* B-1)

Parameter	Symbol	Unit	Left Turn	Right Turn	Average
Steady-state yaw velocity response gain	$(\dot{\psi}/\delta_{\mathrm{H}})_{\mathrm{ss}}$	s^{-1}			
Lateral acceleration response time	T_{ay}	s			
Yaw velocity response time	T_{ψ}	S			
Lateral acceleration peak response time	$T_{\mathrm{aY}}. max$	s			
Yaw velocity peak response	T_{ψ}, max	s			
Overshoot value of lateral acceleration	U_{aY}	-			
Overshoot value of yaw velocity	U_{ψ}	-			

B-2 SINUSOIDAL INPUT

Test number: …………………………….
v_x = 100 km/h   1 ………………km/h
a_y = 4 m/s^2 1 ………………m/s^2
f = 0.5 Hz   1 ……………… Hz

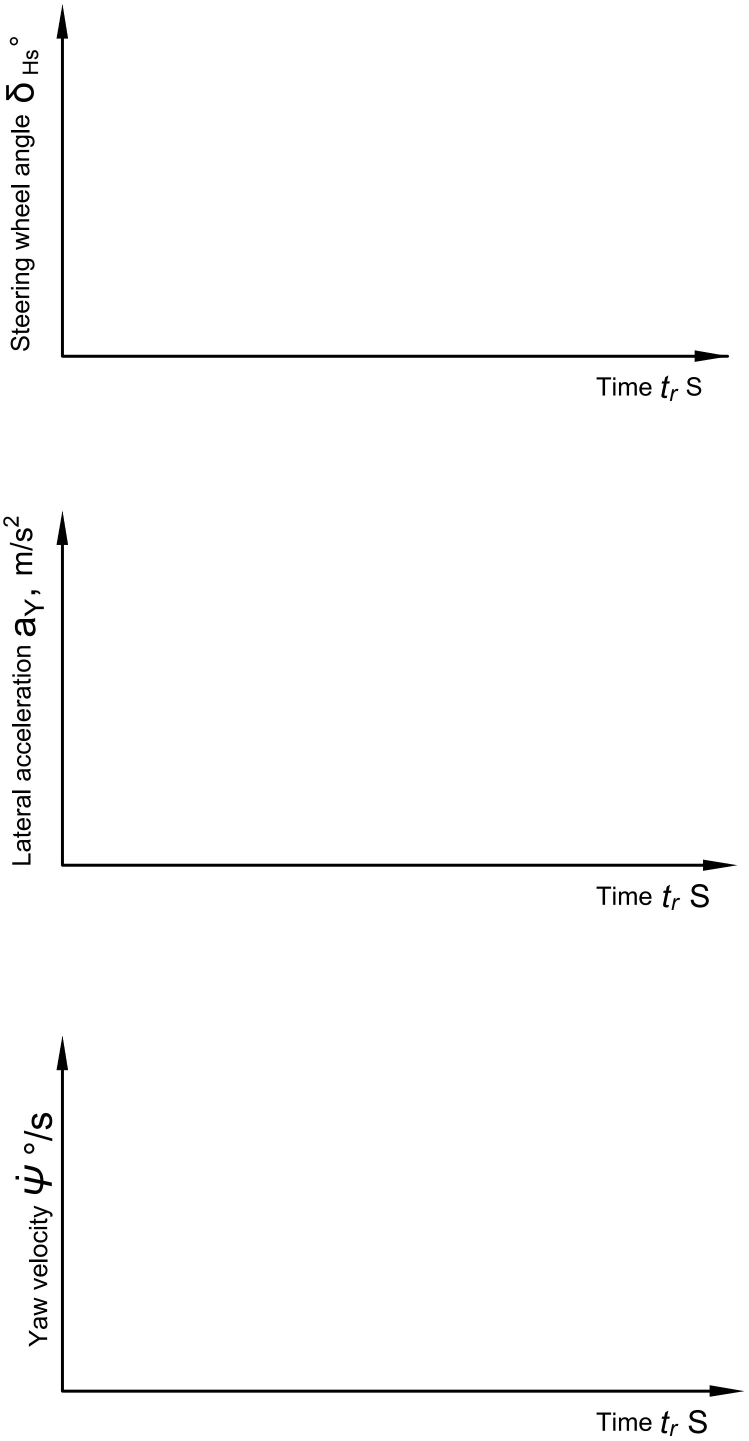


FIG. 32 SINUSOIDAL INPUT (ONE PERIOD) – TIME HISTORIES

Table 10 Sinusoidal Input (One Period) — Response Data Summary

(*Clause* B-1)

Parameter	Symbol	Unit	Left Turn	Right Turn	Average	
Time lag between steering wheel angle and lateral acceleration	$T\,(\mathrm{H} - a_{\mathrm{y}})$		Mean vaule	Standard deviation	Mean value	Standard deviation
Peak 1	$T\,(H - a_{\mathrm{y}})_1$	ms				
Peak 2	$T\,(H - \dot{\psi})_2$	ms				
Time lag between steering wheel angle and yaw velocity	$T\,(H - \dot{\psi})$					
Peak 1	$T\,(\mathrm{H} - a_{\mathrm{y}})_1$	ms				
Peak 2	$T\,(H - \dot{\psi})_2$	ms				
Lateral acceleration gain	$\frac{a_{\mathrm{y}}}{H}$	m/s^2				
yaw velocity gain	$\frac{\dot{\psi}}{\mathrm{H}}$	s^{-1}				

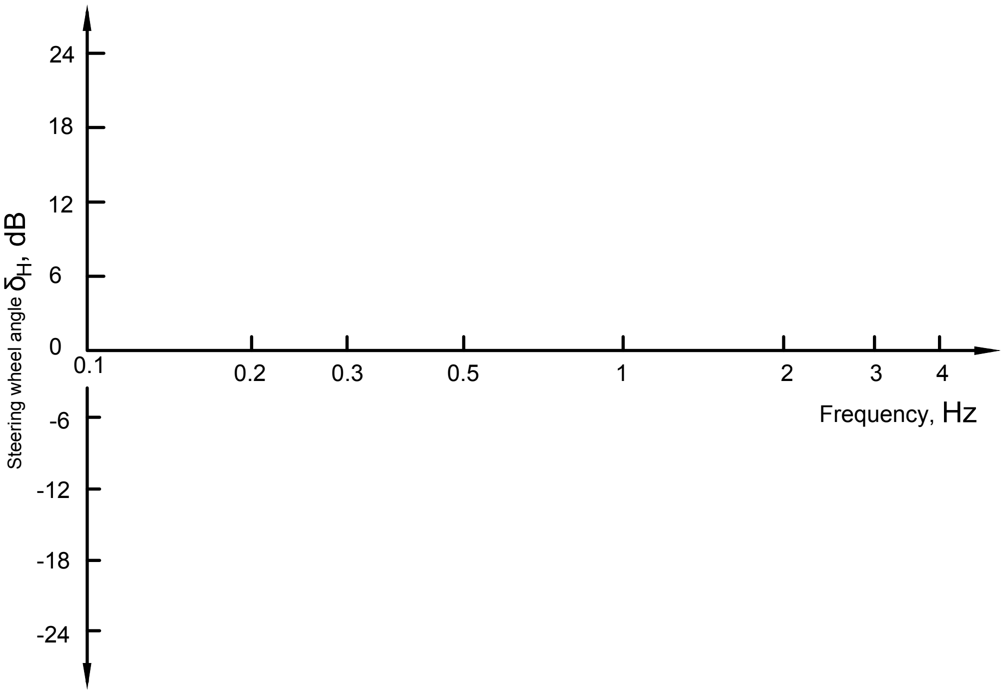
B-3 RANDOM/PULSE[2)] INPUT

Test number: ……………………………

v_{x} = 100 km/h 1 ………………km/h

a_{y} = 4 m/s^2 1 ………………m/s^2

$f = 0.5$ Hz 1 ……………… H



Optional is a linear scale for the frequency (*X-AXIS)*

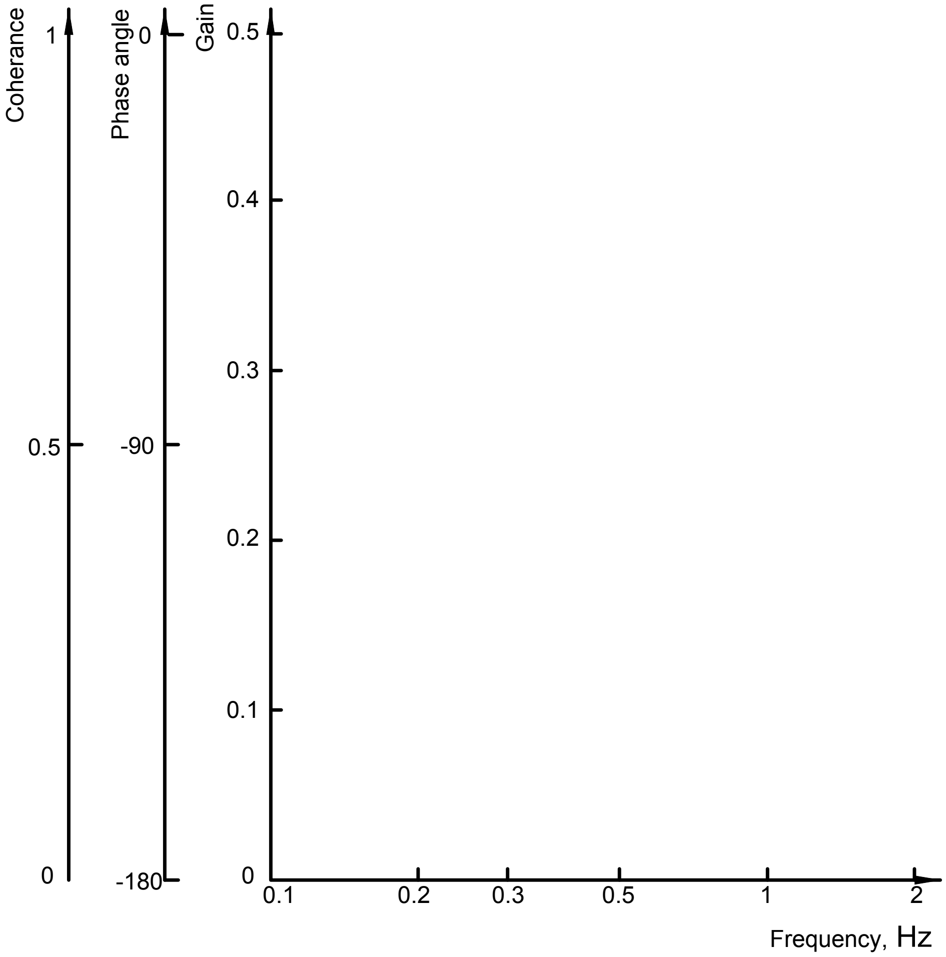
FIG. 33 RANDOM/PULSE INPUT — HARMONIC CONTENT OF STEERING-WHEEL ANGLE

B-4 RANDOM/PULSE/CONTINUOUS[3)] SINUSOIDAL INPUT

Test number: ……………………………

v_x = 100 km/h | ………………km/h

a_y = 4 m/s^2 | ………………m/s^2



Optional is a linear scale for the frequency (*X-Axis)*

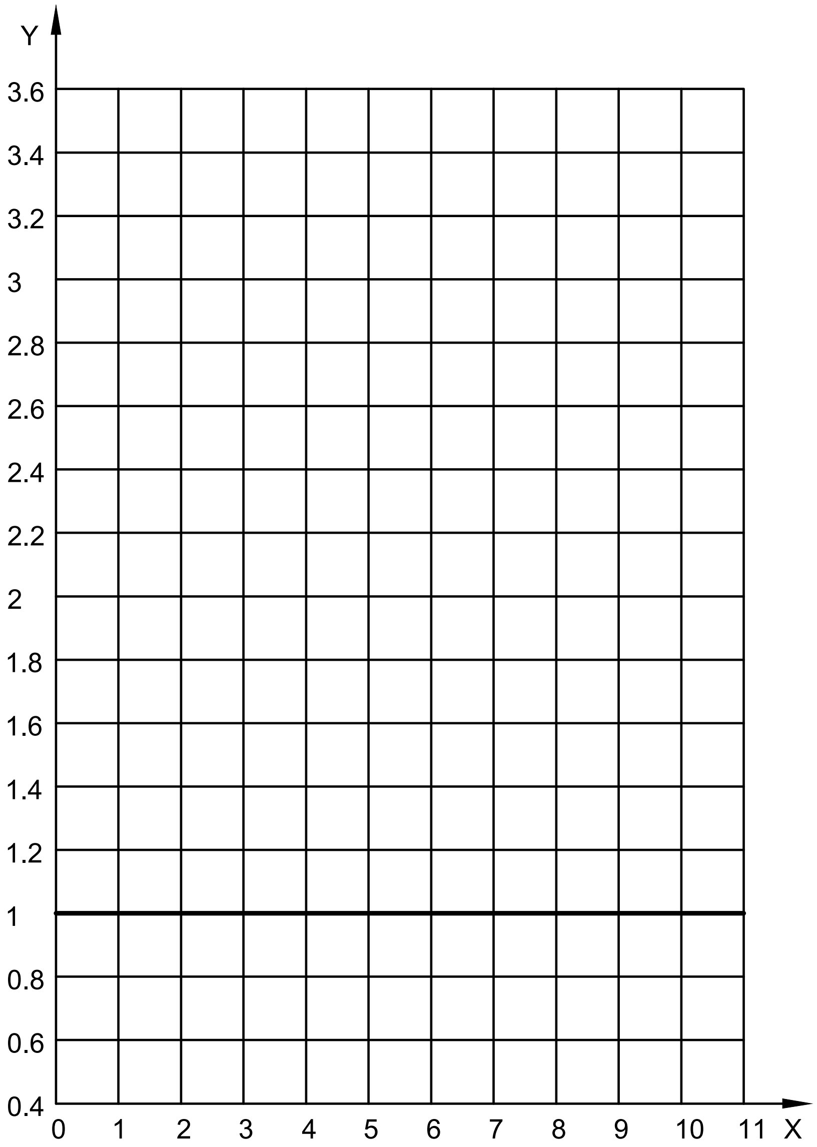
FIG. 34 RANDOM/PULSE/CONTINUOUS SINUSOIDAL INPUT — TRANSIENT RESPONSE TO STEERING-WHEEL ANGLE

ANNEX C

(*Normative*)

C-1 PRESENTATION OF RESULTS

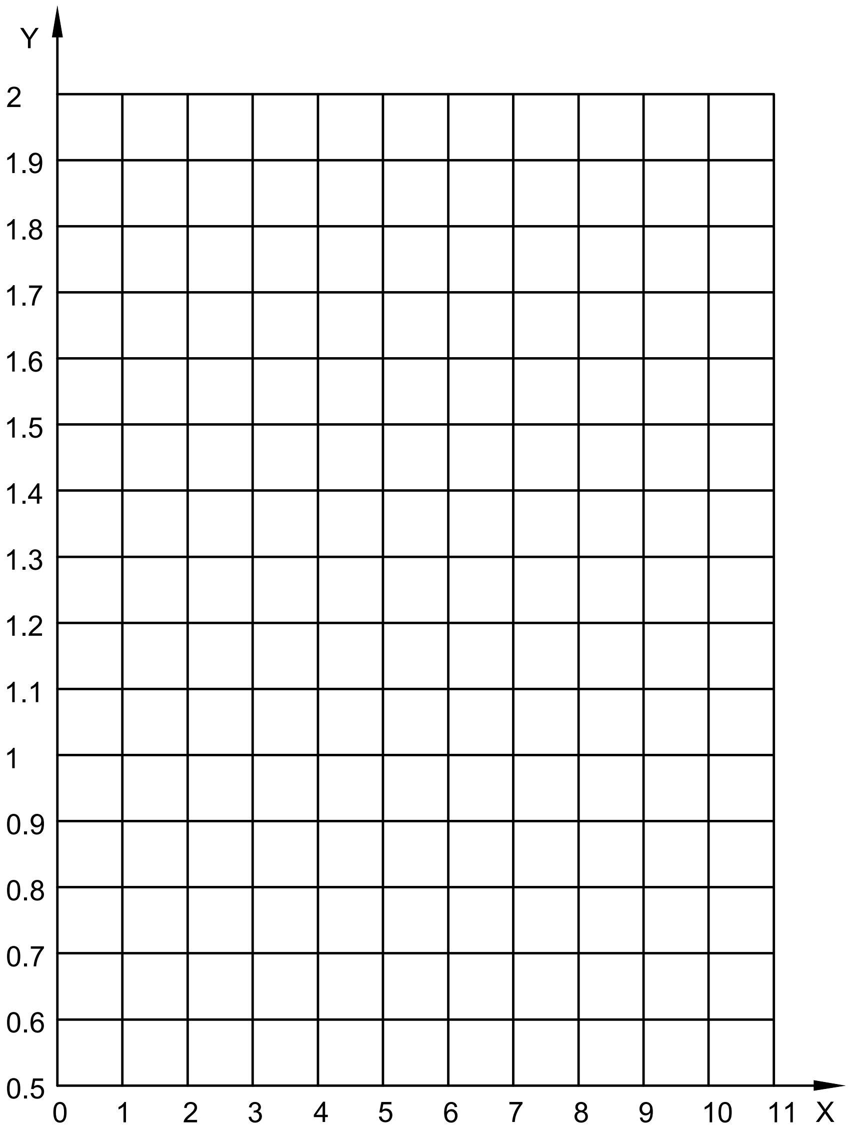
The characteristic values of the vehicle dynamic reaction shall be presented as functions of mean longitudinal acceleration, as shown in Fig. 35 to Fig. 44.



Vehicle
Initial radious:
Time, t_n

X Mean longitudinal acceleration, - $\bar{a}_{x, tn}$ (m/s^2)
Y Ratio of actual to the reference yaw velocity $\frac{\dot{\psi}\ t_n}{\dot{\psi}_{Ref}, t_n}$

Fig. 35 The Ratio of the Value of the Yaw Velocity, $\dot{\psi}\, t_n$ at Time t_n to the Value of the Reference Yaw Velocity $\dot{\psi}_{Ref}$, t_n at Time t_n as a Function of the Mean Longitudinal Acceleration - $\bar{a}_x, t_n$



Vehicle
Initial radious:

X Mean longitudinal acceleration, - $\bar{a}_X$ (m/s^2)

Y Ratio of the maximum yaw velocity to the ref. value at Time t_{max} $\frac{\dot{\psi}_{max}}{\dot{\psi}_{Ref}, t_{max}}$

Fig. 36 The Ratio of the Value of the Yaw Velocity Attained During Breaking, $\dot{\psi}_{max}$ at Time to the Reference Yaw Velocity $\dot{\psi}_{Ref}$, t_{max} at Time t_{max} as a Function of the Mean Longitudinal Acceleration - $\bar{a}_x$

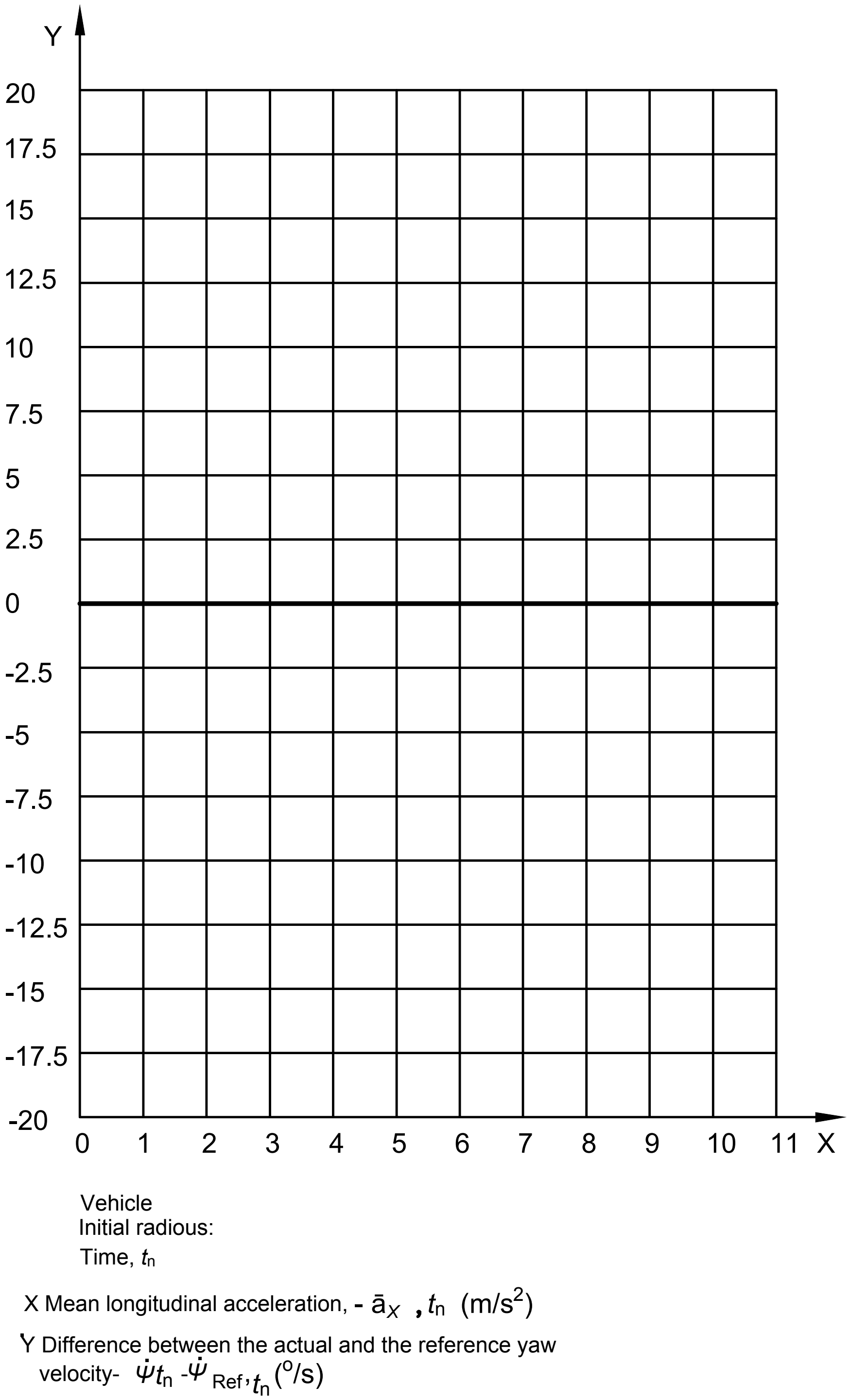
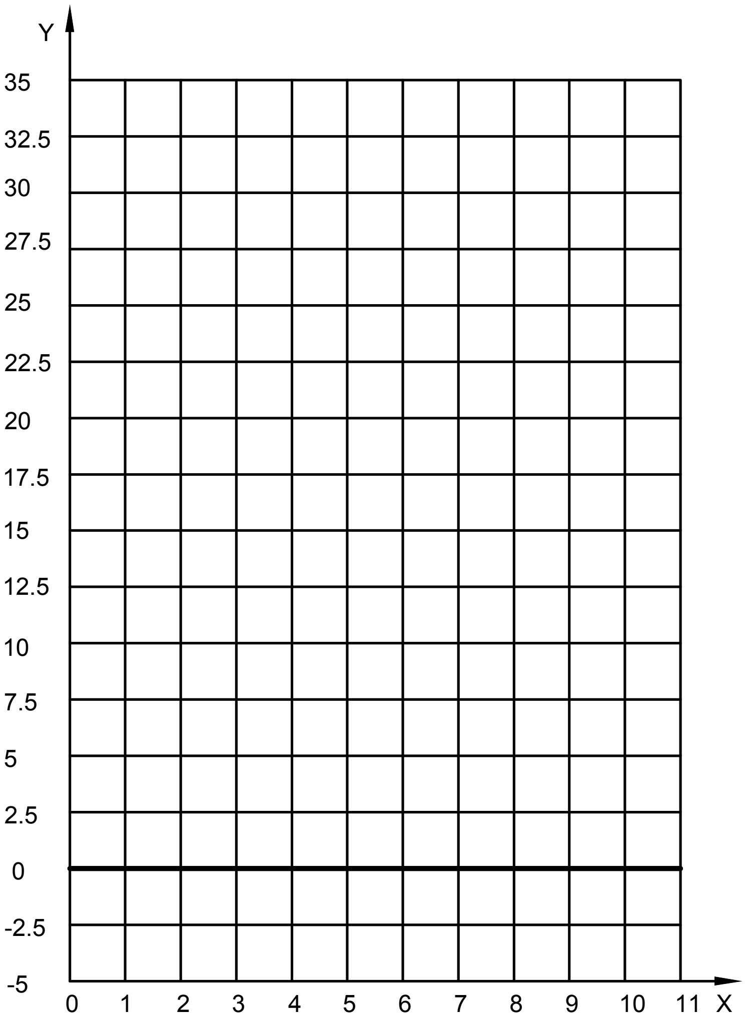


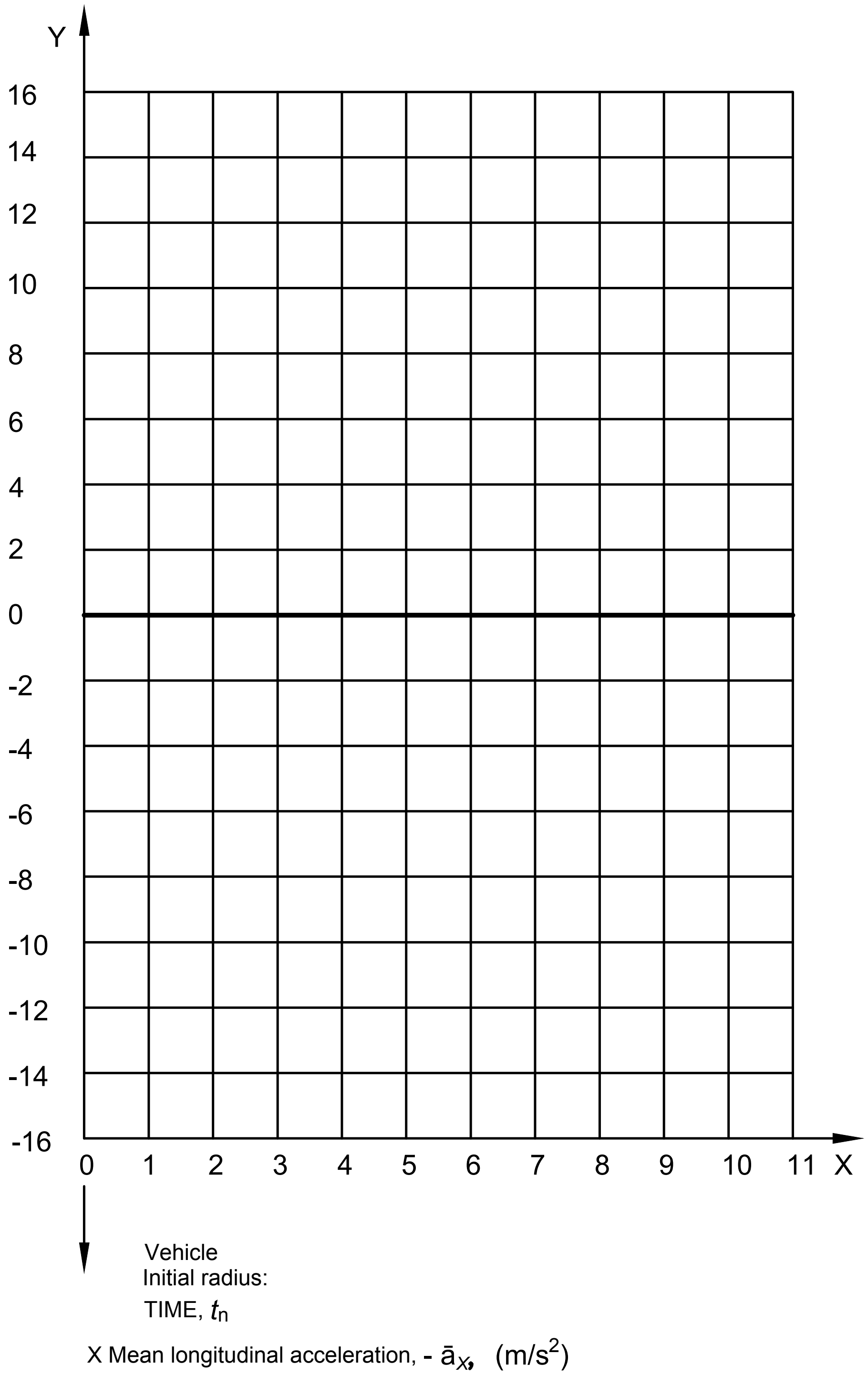
Fig. 37 At Time t_n to the Difference Between the Value of the Yaw Velocity, $\dot{\psi} t_n$ and the Reference Yaw Velocity $\dot{\psi}_{Ref}$, t_n as a Function of the Mean Longitudinal Acceleration - $\bar{a}_x$, t_n



VEHICLE
INITIAL RADIUS:

X MEAN LONGITUDINAL ACCELERATION, - $\bar{a}_X$ (m/s^2)
Y MAXIMUM DIFFERENCE BETWEEN YAW VELOCITY AND REFERENCE YAW VELOCITY, $\Delta\ \dot{\Psi}_{max}$(^{o}/s)

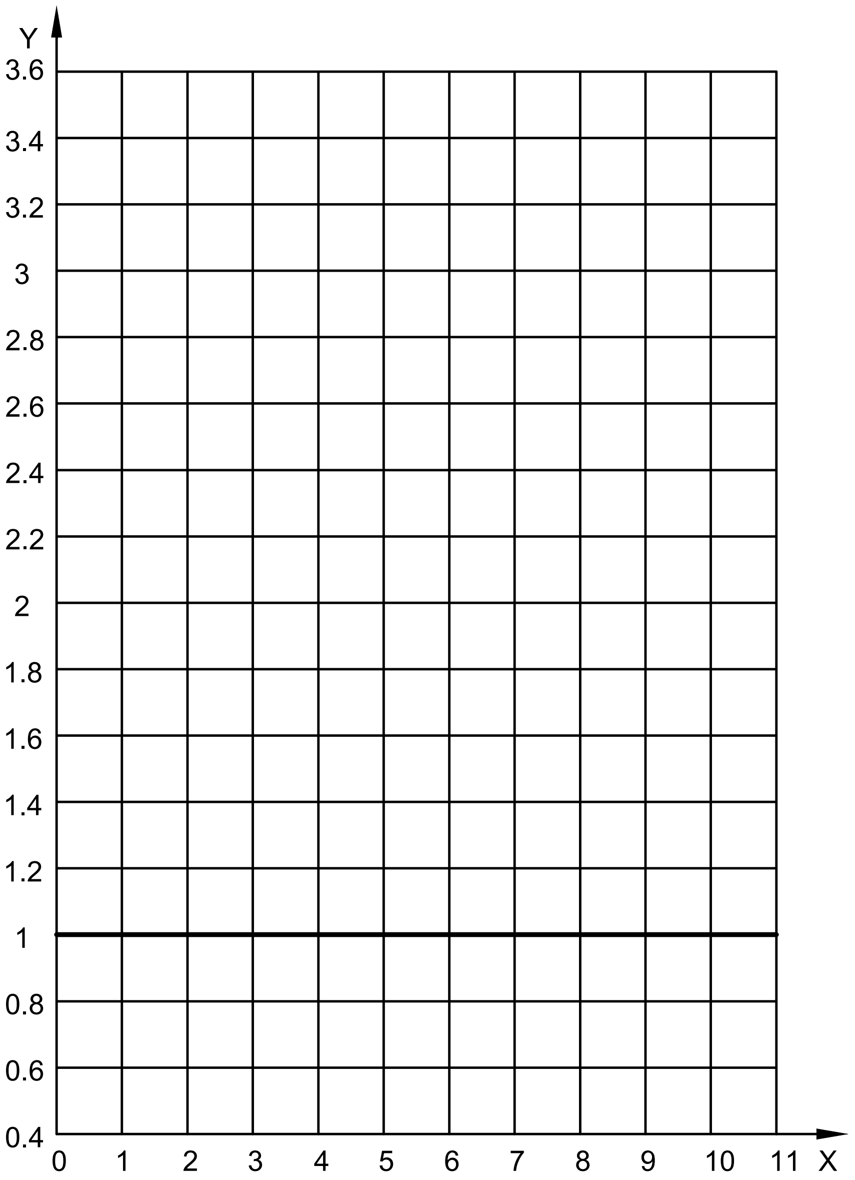
FIG. 38 THEMAXIMUM VALUE OF THE VALUE OF THE DIFFERENCE BETWEEN THE YAW VELOCITY, $\dot{\psi}$, DURING BREAKING AND THE AFFILATED REFERENCE YAW VELOCITY $\dot{\psi}_{Ref}$, AS A FUNCTION OF THE MEAN LONGITUDINAL ACCELERATION - $\bar{a}_x$



X Mean longitudinal acceleration, - $\bar{a}_X$, (m/s^2)

Y Instanteaneous yaw acceleration $\dot{\Psi} t_n$ (^{o}/s^2)

FIG. 39 THE INSTANTNEOUS VALUE OF THE YAW ACCELERATION, $\dot{\psi} t_n$ AT TIME t_n, AS A FUNCTION OF THE MEAN LONGITUDINAL ACCELERATION - $\bar{a}_x$, t_n



Vehicle
Initial radius:
Time, t_n

X Mean longitudinal acceleration, $-\bar{a}_{x}, t_n$ (m/s^2)

Y Ratio of the actual to the reference lateral acceleration $\frac{a_{y,tn}}{a_{y,Ref,tn}}$

FIG. 40 Y RATIO OF THE ACTUAL TO THE REFERENCE LATERAL ACCELERATION, $\dot{\psi}\, t_n$ AT TIME t_n TO THE REFERENCE VALUE OF THE LATERAL ACCELERATION, $a_{y,\ Ref,\ tn}$ AT ACTUAL TIME t_n AS A FUNCTION OF THE MEAN LONGITUDINAL ACCELERATION, $-\bar{a}_x, t_n$

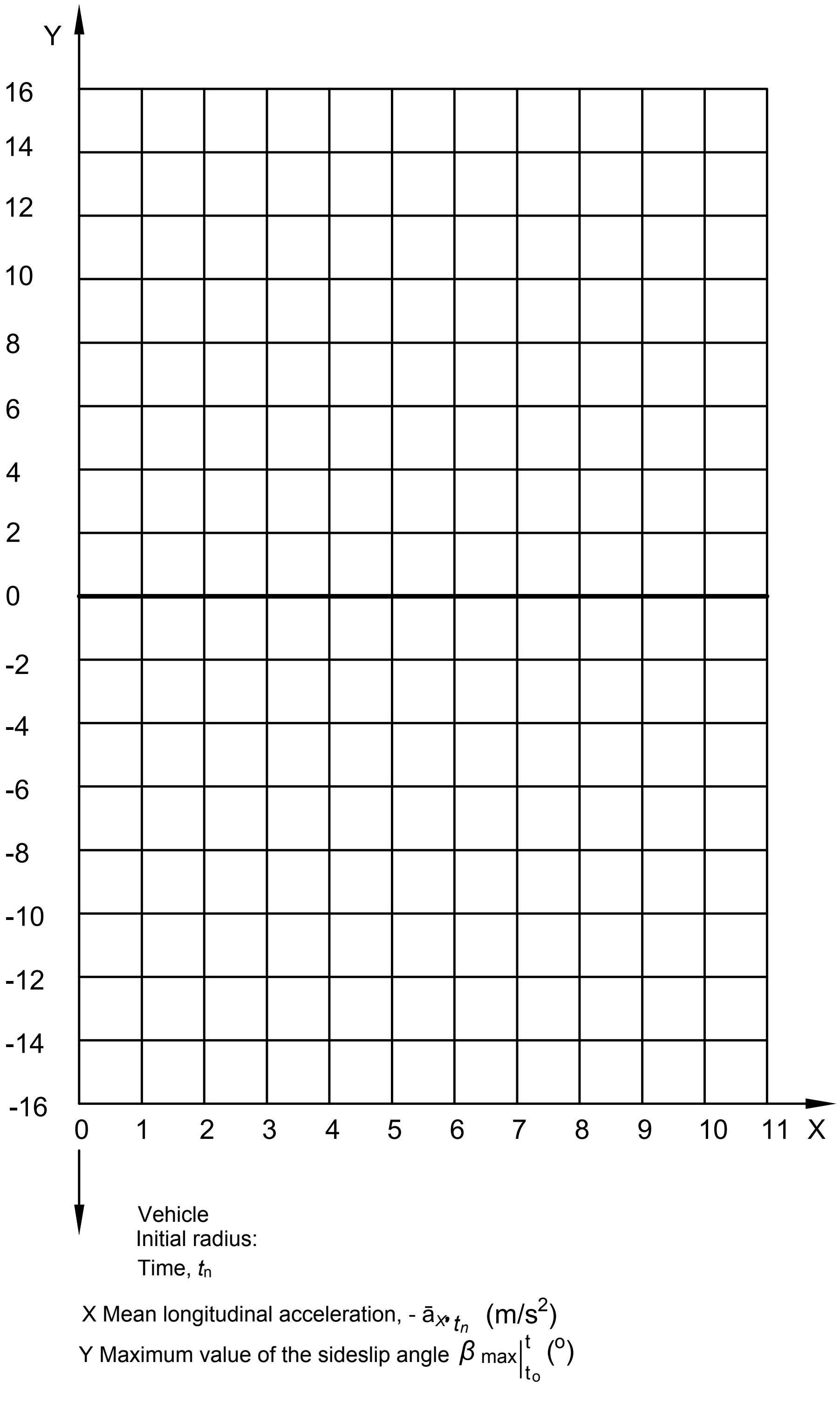


Fig. 41 Maximum Value of the Sideslip Angel $\beta_{max}|_{t_0}^{t}$ (°) During the Observation Period, as a Function of the MeanLongitudinal Acceleration - $\bar{a}_x, t_n$

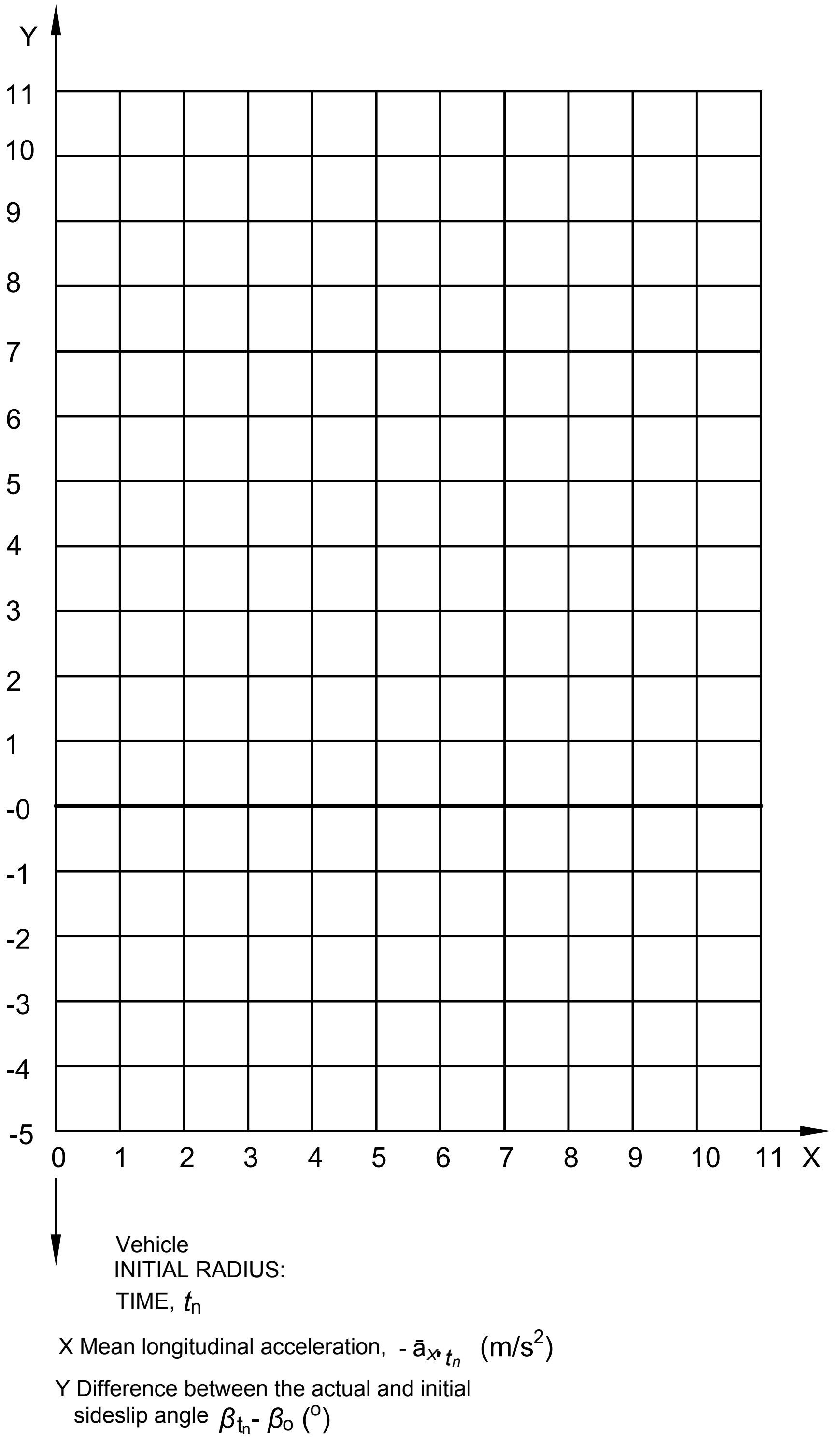
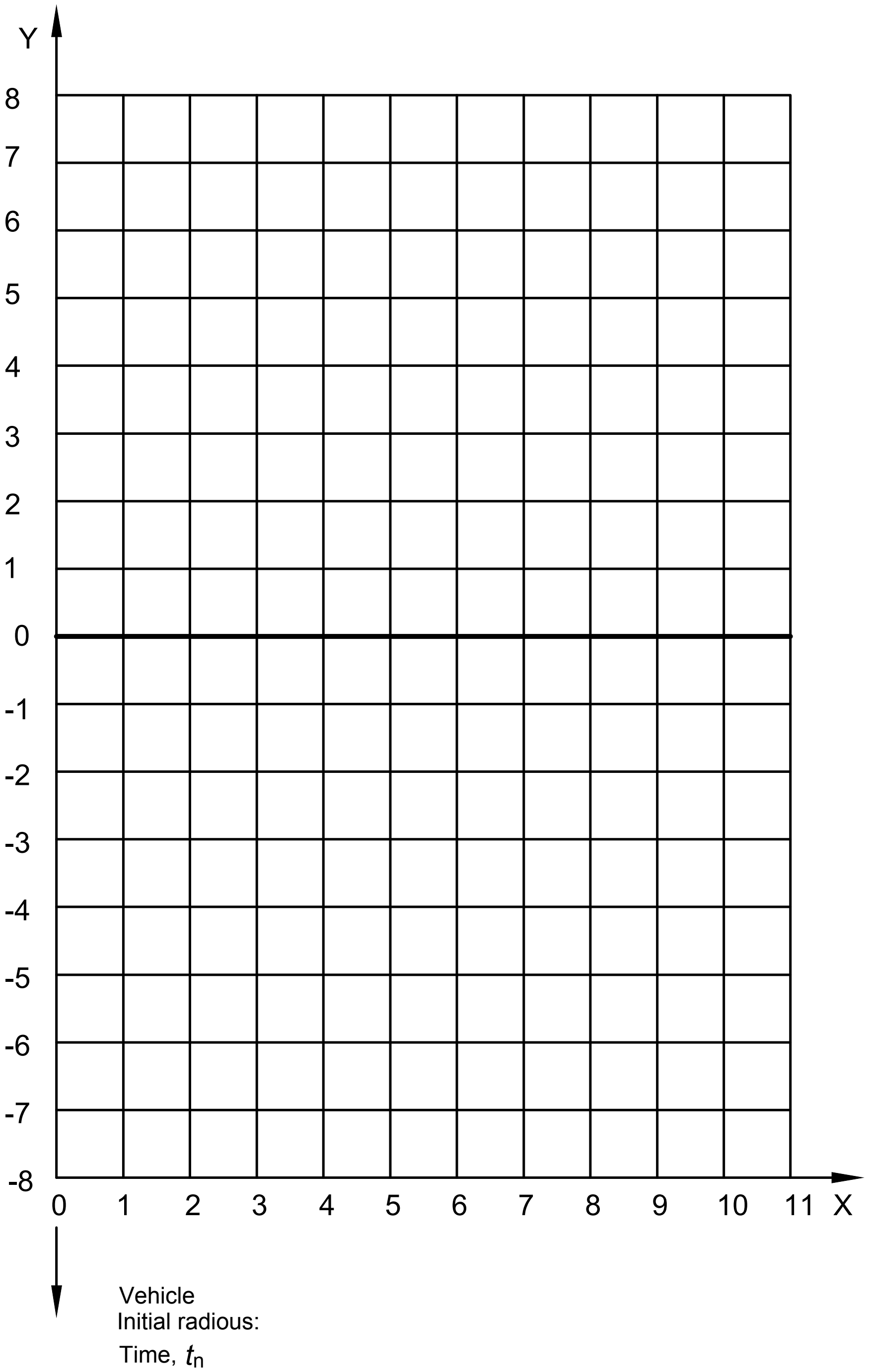


Fig. 42 At Time β_{tn} the Difference Between the Value of the Sideslip Angel β_{tn}, and the Initial Steady-State Value of the Sideslip angle, β_0, as a Function of the MeanLongitudinal Acceleration - $\bar{a}_x$, t_n



X Mean longitudinal acceleration, - $\bar{a}_X$, t_n (m/s^2)

Y Actual sideslip angle velocity β_{tn} (Uncorrected) (°/s)

FIG. 43 AT TIME t_n, THE DIFFERENCE BETWEEN THE VALUE OF THE YAW VELOCITY, $\dot{\psi} t_n$ AND THE CALCULATED YAW VELOCITY, AS A FUNCTION OF THE MEAN LONGITUDINAL ACCELERATION - $\bar{a}_x$, t_n (UNCORRECTED SIDESLEEP VELOCITY)

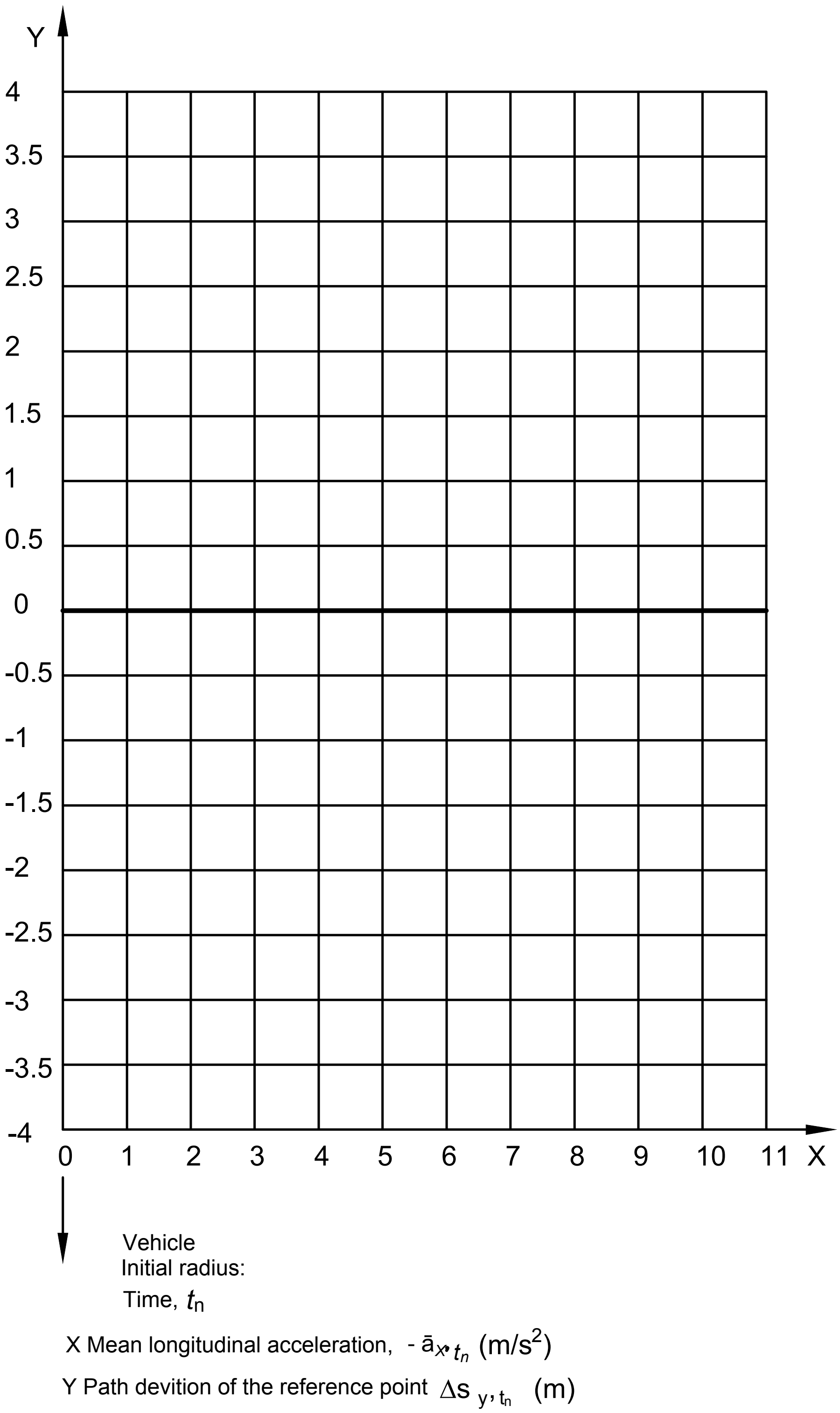


FIG. 44 AT TIME t_n, THE PATCH OF THE DEVIATION OF THE REFERENCE POINT ΔS y, t_n, AS A FUNCTION OF THE MEAN LONGITUDINAL ACCELERATION - $\bar{a}_x$, t_n

ANNEX D

(*Foreword*)

COMMITTEE COMPOSITION

Automotive Braking Systems, Vehicle Testing and Performance Evaluation Sectional Committee, TED 04

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Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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